CHEMICAL ENGINEERING 03 CORROSION MONITORING • PROCESS SAFETY VOL. 126 NO. 3 MARCH 2019

CHEMICAL ENGINEERING

ESSENTIALS FOR THE CPI PROFESSIONAL

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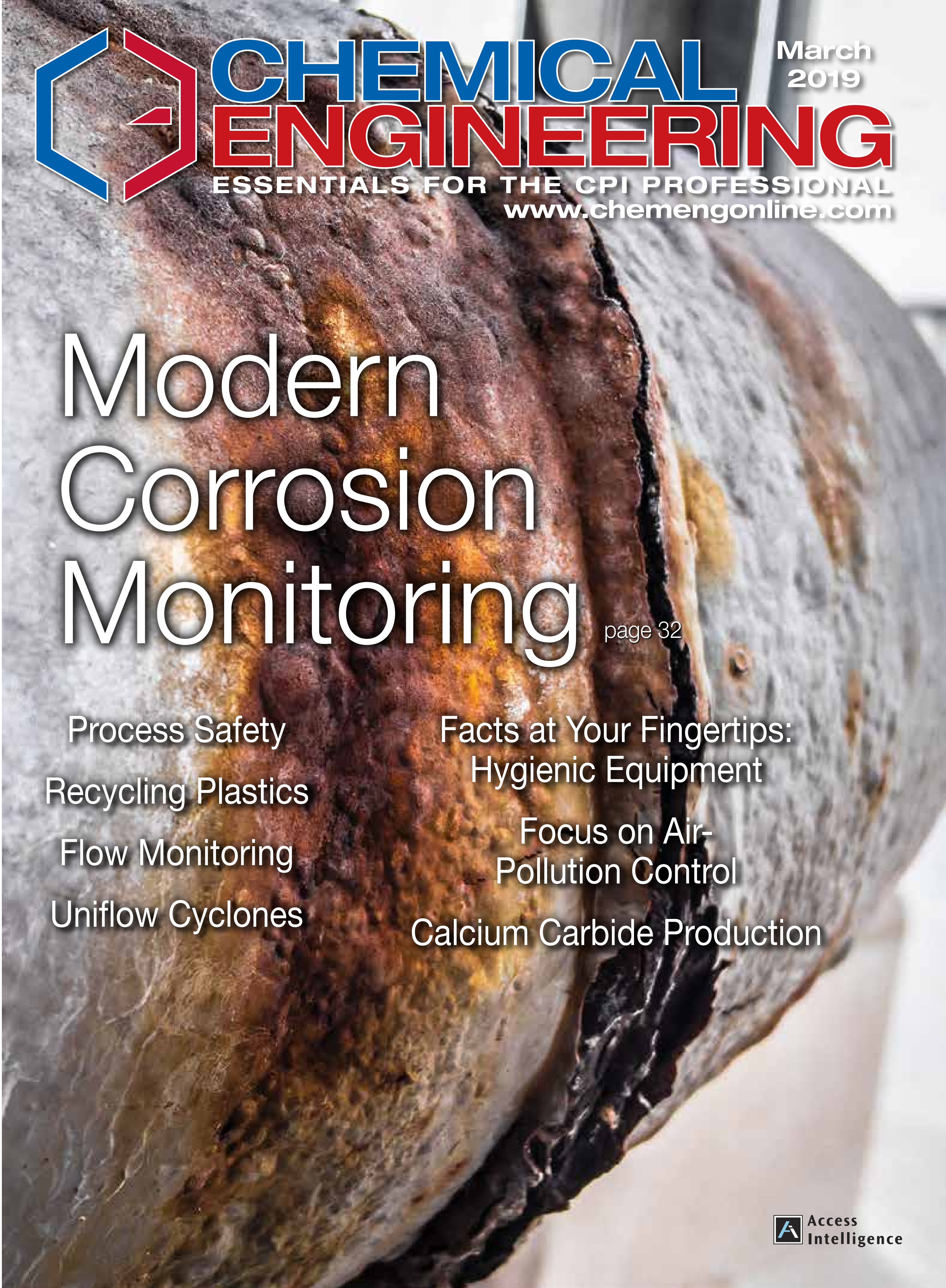

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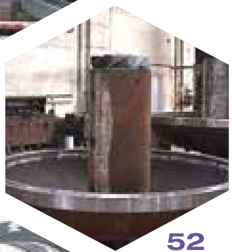
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Cover design: Rob Hudgins

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Editor's Page

Game Changers

The technologies associated with the Industrial Internet of Things, and the benefits that can be attained from them, are topics that are frequently described in the pages of *Chemical Engineering*. Finding and implementing the best new technologies for an application takes focus, insight and often the willingness to take a chance on a new approach. Last month, at the Connected Plant Conference (www.connectedplantconference.com), 11 individuals and teams were recognized for their roles in moving the dial toward digitalization in the chemical process and energy industries. The "Game Changers," listed below include innovators, problem solvers and fast risers or champions in digitalization.

Jonathan Alexander, Albemarle Corporation — Alexander initiated and managed the transformation of two specialty chemical plants within Albemarle by successfully implementing realtime analytics. He involved operators and supervisors in selecting which process variables to analyze and how to respond to analytics-based signals.

Amber Hayton, Royal Dutch Shell — Hayton has been leading development activities for digitalization of Shell's learning portfolio. Expert knowledge is being captured and digitalized via a virtual-reality learning platform, which is being built for both local and cloud use to make it globally applicable.

Nexceris Sensors Group — This group's innovative sensor monitors emissions from lithium-ion batteries that indicate when the battery is faulty. It can cut the current to the battery before it starts a fire, making it a very useful safety tool for energy storage — an ever-growing application.

Robinson Castillo, Florida Power & Light Co. — Castillo was a pioneer in spearheading the use of wireless technology in the power industry at a time when it was new and met with much skepticism.

Joan Knight and Grant Brummels, Exelon — Knight and Brummels led the implementation of GE Predix, as well as other digital initiatives in Exelon's nuclear and fossil generation businesses.

Ted Gutierrez, SecurityGate — This company has developed a software platform that simplifies cyber risk assessments so that users can focus on mitigating cyber risks rather than finding them.

Johnny Howze III, Georgia Power Co. — Howze has been pioneering turning Plant Scherer, the largest coal-fired plant in the U.S., into the connected plant of the future. His vision is based on two principles: the need to prepare the workforce of tomorrow; and the need for a digitized plant and processes.

Asset Management Office, Nova Scotia Power — Through their efforts in digitalization, this office has been able to provide its fleet of power-generation plants with insight about potential problems and to help with capital planning and investment decisions.

ProAxion, Inc. — This innovative startup developed a system that simplifies the process of measuring, transmitting and analyzing vibration and temperature data for remote monitoring of rotating machines.

Michael Reid, Duke Energy — Reid oversees technical programs for Duke Energy where data analytics are being used for everything from routine to predictive maintenance.

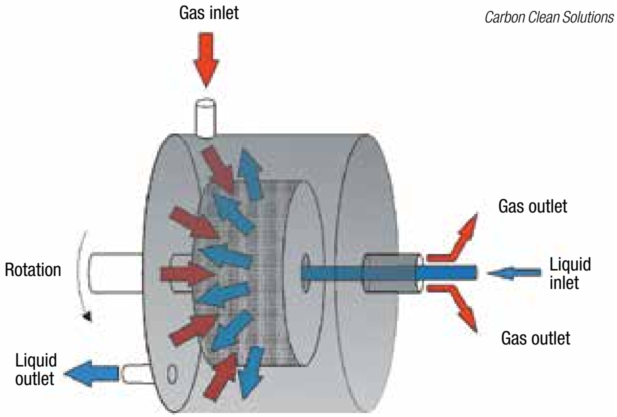
Leo Simonovich, Siemens Energy — Simonovich is responsible for the direction of cybersecurity efforts for Siemens Energy, with an emphasis on global critical infrastructure, and has been a leader with Siemens global Charter of Trust cybersecurity framework. ■

Dorothy Lozowski, Editorial Director

Process intensification for carbon capture could reduce costs

Edited by:
Gerald Ondrey

In conventional solvent-based carbon-capture systems, CO_2-rich exhaust gas contacts gravity-driven solvents in a vertical packed-bed column. A novel approach developed by Carbon Clean Solutions USA Inc. (CCSUS; Cumming, Ga.; www.carboncleansolutions.com) employs centrifugal force from rotating horizontal packed beds to effect the gas-to-liquid contact. The higher *g*-forces allowed by the rotation improve mass transfer and enable smaller units to be used. Smaller units would lower capital costs compared to traditional carbon capture. The system has the potential to reduce the levelized CO_2-capture cost to the U.S. Dept. of Energy (DOE) target of $30/ton or less.



Under a $2.9-million cooperative agreement from the DOE's National Energy Technology Laboratory, GTI (Des Plaines, Ill.; www.gti.energy) is the prime contractor leading the effort with CCSUS to scale up this process-intensification approach from laboratory scale size to a larger, integrated carbon-capture system capable of removing 1 ton/d CO_2 from power-plant fluegas.

The novel carbon-capture approach, known as ROTA-CAP technology, is designed such that CCS's intensified solvents are pumped into the center of the rotating cylinder, and the centrifugal force from the rotation pushes the liquid outward through the packed-bed gas-liquid contactor (diagram). The CO_2-containing fluegas flows from the exterior of the cylinder, against the flow of solvent.

"A key feature of ROTA-CAP is its use of more highly concentrated solvents than those used in conventional carbon capture," says David Bahr, CCSUS technology manager, and that can reduce the energy required for regeneration of the CO_2. Although the overall energy savings are partially offset by the rotational energy required in the packed-bed cylinders, validation tests indicate up to 45% energy savings compared to conventional monoethanolamine (MEA) units.

GTI and CCSUS are now designing the larger-scale system, and anticipate completing construction by mid-2019. After laboratory testing at GTI headquarters, the assembly will be moved to the National Carbon Capture Center in Wilsonville, Ala. for long-term testing. "While the current project is focused on capturing CO_2 from fluegas at coal- and natural-gas-fired power plants, the rotating packed-bed intensification approach could be applied to other industrial operations involving gas-liquid contact," notes GTI technology manager Osman Akpolat.

ANG FUELING STATION

Ingevity (North Charleston, S.C.; www.ingevity.com) has completed construction of a fueling station for low-pressure adsorbed natural gas (ANG) at its headquarters in North Charleston, S.C. The fueling station will supply natural gas to ANG bi-fuel vehicles outfitted with storage cylinders containing Ingevity's Nuchar FuelSorb activated carbon monoliths. Bi-fuel vehicles have internal combustion engines that can operate on either natural gas or gasoline. ANG technology is made possible by Ingevity's activated carbon, which reduces the storage pressure of natural gas without sacrificing the volume of gas stored through an adsorption process. For more information, see *Chem. Eng.*, August 2017, p. 10.

NITROGEN FIXATION

A team from South China University of Technology (Guangzhou, China; https//en.scut.edu.cn), led by professor Haihui Wang, has discovered that black phosphorus — phosphorus in its lowest reactivity, nontoxic form — is an excellent catalyst for the electro-reduction of nitrogen to ammonia. The team found that the zigzag

(Continues on p. 8)

Mechanical CO_2 sequestration improves algae production

A new, mechanical method for sequestration of carbon dioxide into water was evaluated at the University of Texas' (Austin; www.utexas.edu) Bioproducts and Bioenergy Analytical Service Center and has revealed a pathway to economically improve algae growth for production of oils. "Existing sequestration technology generally uses some type of sparger to dissolve CO_2 in water and make it available to algae. Much of the gas is not dissolved and escapes back into the atmosphere. Our technology results in a supersaturated CO_2-water environment where CO_2 is more available to algae, resulting in a 95% increase in algae growth," says Gregory Borsinger, one of the inventors of the technology.

The new system employs a rotor-stator device that is operated under conditions that are thought to induce cavitation, which results in the supersaturation of gases into liquids. The highly saturated CO_2 solution creates an environment of maximized photosynthetic productivity for algae production — in laboratory trials, the CO_2 saturated in the media was consumed for algae production in just 24 hours.

According to Borsinger, the team from the University of Texas has observed unprecedented increases in algae growth using this new technology when compared to other CO_2-delivery mechanisms. Additionally, the technology was applied to algae oil harvesting and demonstrated cell lysing of over 80%. Currently, the technology has been demonstrated in the laboratory, and the developers are actively working toward commercialization.

arrangement in the phosphorus layers, in contrast to other layered or flat materials, provides ideal sites for nitrogen adsorption and the electronic structure at the edges was best suited for binding, activating and reducing nitrogen by a low-energy pathway.

The team included the catalyst nanosheets in a carbon-fiber electrode for electrolysis. To provide a nitrogen supply, a hydrochloride electrolyte solution was saturated with nitrogen. On application of a voltage, the electrode readily and selectively produced ammonia from nitrogen. Wang says the layered black phosphorus even outperformed most nonmetallic and metal-based catalysts lately reported.

A drawback of black phosphorus is that its performance declines in the long term due to oxidation, so it will be necessary to find ways of preventing degradation in the electrolyte, says the team.

BIO-BASED MEG

Braskem (São Paulo, Brazil; www.braskem.co/br) and Haldor Topsoe S/A (Lyngby, Denmark; www.topsoe.com) have reached mechanical completion of the MOnoSAccharide Industrlal Cracker (Mosaik) process step of their demonstration plant that will produce bio-based monoethylene glycol (MEG) from sugars. Mosaik is a method for cracking sugars into an intermediary product, which can be further converted to MEG or other biochemicals, such as methyl vinyl glycolate or glycolic acid, using Topsoe's patented processes and catalysts.

The demonstration plant, located in Lyngby, Denmark, is an important step to upscale the Mosaik process and begin production at an industrial scale, which is planned to commence in 2023. The plant can produce more than 100 ton/yr of glycolaldehyde, which is converted into MEG in the next process step.

DAIRY BIOREFINERY

Whey permeate (WP) and delactosed whey permeate (DLP)

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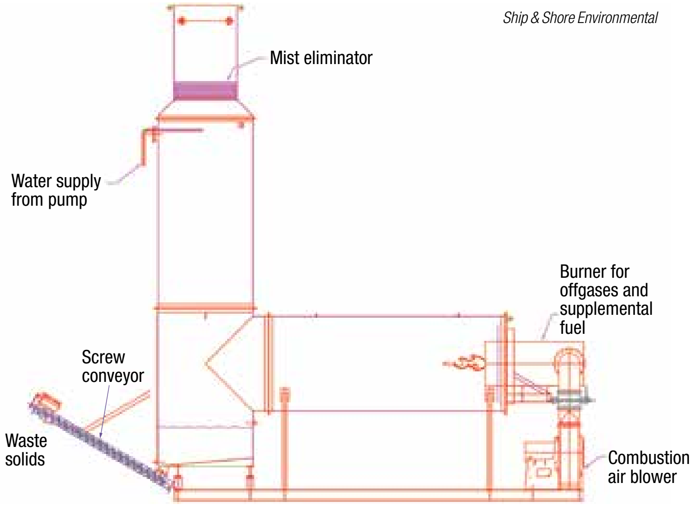
A single process to handle hydraulic fracturing produced water and offgases



Two major concerns in hydraulic fracturing operations are finding efficient ways to handle the massive amount of produced wastewater, and dealing with offgases from the well. A new technology developed by Ship & Shore Environmental Inc. (Signal Hill, Calif.; www.shipandshore.com), in partnership with Hydrozonix LLC (Conroe, Tex.; www.hydrozonix.com), employs an enclosed flare to destroy the well offgases and harvests the resulting energy to evaporate wastewater. According to Mike Pawlowski, senior technical sales manager at Ship & Shore Environmental, this the first technology available to the hydraulic fracturing market for onsite evaporation of produced water. The process — called Hydroflare — works by connecting the source of well offgases to an enclosed flare burner. "The resultant heat from the flare is passed to a tower or stack, which includes spray nozzles to mist the produced water into the high-temperature discharge of the burner section," explains Pawlowski. A conveyor is also provided to discharge any solids present in the liquid stream for solid-waste disposal.

The Hydroflare technology will be especially useful for hydraulic fracturing sites that have difficulty in removing wastewater via trucks, or those that must use enclosed flares to treat offgases, says Pawlowski. The Hydroflare enclosed flare is said to achieve a destruction efficiency for offgases of 99% or higher. Pawlowski notes that water disposal capacity is limited to the amount of offgas present or by the availability of supplemental fuel. The technology can be "dropped in" to existing sites, provided that ground support and proper utilities are in place. The first Hydroflare system was recently installed at a 1,000-bbl/d production site in Texas.

New membranes resist biofouling using sunlight

Membranes in large-scale water-treatment processes are often fouled by accumulation of bacteria or their biofilms. Now, a team of researchers from Washington University St. Louis (WUSTL; St. Louis, Mo.; www.wustl.edu) have combined graphene oxide and bacterial nanocellulose to design a highly efficient ultrafiltration membrane that resists biofouling. "Photothermal nanomaterials like graphene oxide absorb light effectively, and the absorbed light is quickly converted into heat. Thus, the membrane gets hot, killing microorganisms on its surface and minimizing biofilm formation. This new membrane design uses the natural energy of sunlight to resist biofouling on membranes," explains Young-Shin Jun, professor of Energy, Environmental & Chemical Engineering at WUSTL. Previously reported nanomaterial-enabled membranes often suffer from short operational lifetimes and poor physical and chemical stability that can result in nanomaterials leaching into water, adds Srikanth Singamaneni, professor of Mechanical Engineering and Materials Science at WUSTL. To secure the photothermal materials within the membrane's structure, the team from WUSTL started with a bacterial culture medium where cellulose nanofibers grow into a matrix. Next, as graphene oxide nanosheets are incorporated into the medium, the bacteria build a nanocellulose matrix with embedded graphene oxide. "You end up with a composite membrane consisting of interlocked graphene oxide and nanocellulose, so particulate matter from the membrane itself does not leach out into the water," adds Singamaneni.

According to Jun, combining the bacteria-killing properties of photothermal materials with the mechanical and chemical integrity of a nanocellulose network results in a membrane with a longer life and higher liquid flux than commercially available membranes operating at the same pressure. The team believes that the new membranes will be readily scalable, since the technology depends on culturing bacterial nanocellulose, a process that is already conducted at large scales.

are major byproducts of dairy processing and represent a key challenge for the dairy industry due to a lack of reliability in current disposal routes, and represent a sustainability bottleneck for the expansion of milk production in Europe. In an effort to valorize such waste, a new E.U.-funded project — dubbed AgriChemWhey — started last month. AgriChemWhey is testing and proving the techno-economic viability of converting agriculture and agri-food waste into sustainable lactic acid at a first-of-its-kind biorefinery. The industrial-scale biorefinery is to be located in the South East region of Ireland, and will have the capacity to valorize over 25,000 metric tons per year (100% dry matter) of excess WP and DLP.

Representing the first major industrial venture to convert residues from food processing, the flagship plant in Ireland will scale-up a unique fermentation processes of WP/DLP-to-lactic acid (LA) by reducing the fermentation time to a 12-h process, optimizing the upstream processes of DLP and WP and optimizing the downstream steps for simplified LA purification at industrial scale. The process was developed by Agrichem-

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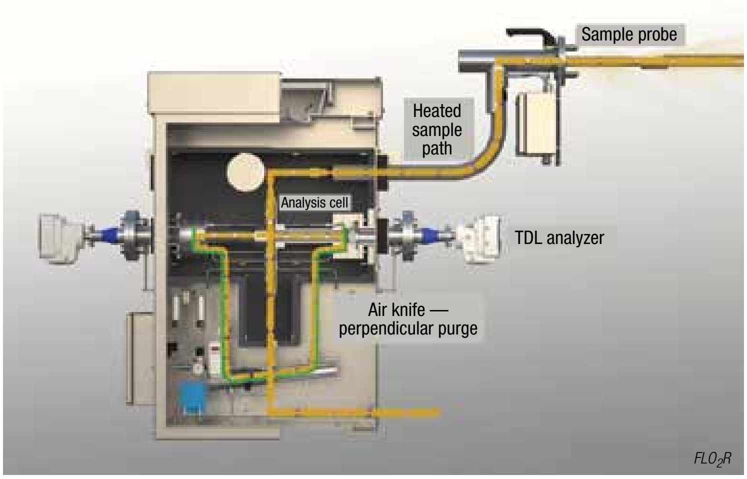
Gas analysis made easier for high-dust areas



FLO$_2$R

A collaboration between Servomex (Surrey, U.K.; www.servomex.com) and FLO$_2$R (Hadsund, Denmark; www.flo2r.com) has resulted in the industry's first laser-based gas-analysis system for use in high-dust environments. Tunable diode laser (TDL) technology provides a much more rapid response than conventional extractive systems for gas analysis, but it historically has been infeasible for use in applications where dust is present, since TDL systems rely on light visibility, and the presence of dust can inhibit laser transmittance, says Karsten Brink Floor, managing director of FLO2R. The new Hybrid 600 system (diagram) incorporates optics that minimize light loss in dusty conditions and also a built-in air knife that protects optic elements from process gases.

Furthermore, dust-heavy applications typically require large ducts, and installation of laser systems is usually limited to smaller duct sizes, but Floor explains that the new Hybrid 600 system uses a unique single-flange mounting configuration that enables its setup in ducts of any size, in applications with dust loads as high as 200 g/m^3. Floor envisions that the Hybrid 600 system will fulfill two critical gas-analysis needs — safety interlocking applications and emissions control.

Commercial trials of the new system were recently completed at the Aalborg Portland cement plant in Denmark, where Hybrid 600 technology was used to monitor carbon monoxide levels on two kiln lines to ensure that excessive CO volumes would not lead to explosive conditions, based on the plant's safety interlocking limits. Key to ensuring a safe installation, according to Floor, was to determine the optimal measuring point for CO, which, in this case, was as close as possible to the CO's origin in the pre-heater system, where dust loads may vary between 75 and 200 g/m^3. Floor expects to roll out the technology into waste incinerators, power plants and clay-burning kilns in the coming months.

A new, more comprehensive electronegativity scale

The electronegativity of atoms is one of the most well-known parameters for explaining why chemical reactions occur. Now, Martin Rahm, assistant professor of physical chemistry at Chalmers University of Technology (Gothenburg, Sweden; www.chalmers.se), has redefined the concept with a new, more comprehensive scale. His work, undertaken with colleagues Tao Zeng at Carleton University (Ottawa, Ont., Canada; www.carleton.ca) and Roald Hoffmann at Cornell University (Ithaca, N.Y.; www.cornell.edu), was published in a recent issue of *J. Am. Chem. Soc.*

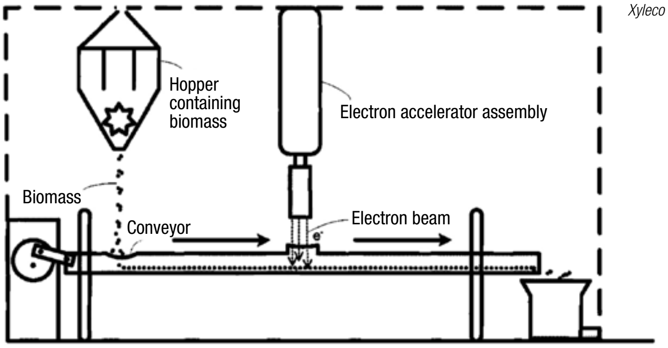
Numerous electronegativity scales have been developed since the concept was first proposed by Swedish chemist Jöns Jacob Berzelius in the 19th century, but most of these scales only cover parts of the periodic table, typically omitting various heavy or heaviest elements. The new scale covers elements 1 to 96 — the most comprehensive to date.

"The new definition is the average binding energy of the outermost and weakest-bound electrons — commonly known as the valence electrons," explains Rahm. "We derived these values by combining experimental photoionization data with quantum mechanical calculations. By and large, most elements relate to each other in the same way as in earlier scales. But the new definition has also led to some interesting changes where atoms have switched places in the order of electronegativity. Additionally, for some elements, this is the first time their electronegativity has been calculated," says Rahm.

For example, compared to earlier scales, manganese and zinc have both been moved in the ranking, relative to elements closest to them in the periodic table. Fluorine is still the most electronegative element in the new scale, but it is 1.3 eV less electronegative than helium, which helps to explain the non-existence of helium fluorides.

One challenge with electronegativity as a concept is that it is sometimes unable to predict chemical reactivity or the polarity of chemical bonds. A further advantage of the new definition is how it fits into a wider framework that can help explain what happens when chemical reactions are not controlled by electronegativity, says Rahm.

Accelerated electrons unlock sugars from cellulosic biomass



Xyleco

Obtaining sugars from cellulosic biomass cost-effectively is difficult because the predominant biopolymers in plant material evolved to protect these sugars. A process currently being scaled up for obtaining sugars from waste agricultural biomass employs beams of accelerated electrons to fracture chains of cellulose and hemicellulose, allowing dramatically improved enzymatic hydrolysis in subsequent process steps.

Xyleco, Inc. (Wakefield, Mass.; www.xyleco.com) is building a commercial-scale demonstration plant in Moses Lake, Wash. to make several end products at 10 times the volume of its initial pilot plant. The process consists of three major steps. First, waste agricultural biomass, such as corn cobs, corn stover, sugarcane bagasse and others, are milled to a particular particle-size range, depending on the feedstock used. Next, the biomass is passed below a beam of accelerated electrons, which collide with the atoms of the biomass, causing electrons to be ejected from the plant material (diagram).

"The collisions, and subsequent ejection of electrons leave the material in an ionized state," explains Craig Masterman, Xyleco's chief technology officer. "This charged state is unstable, so the long chains that make up the polymer strands of the biomass fracture and break apart."

The molecular weight of the polymers is reduced in this way by 95% or more, Masterman says, although to the naked eye, the processed material appears identical to the starting biomass. Because the biopolymers are broken down by the electron beam, the third stage of the process — an enzymatic hydrolysis step with a proprietary mix of enzymes that yields sugars — is more efficient by a factor of 10 compared to untreated biomass and significantly more productive than biomass treated with acids. The predominant sugars obtained are xylose and glucose, which can be fermented or otherwise chemically transformed into a range of products, including ethanol, polylactic acid, succinic acid and others.

The key advantages of the process include relatively low-cost process equipment (no high temperatures or pressures are required), low water use and waste production, fast processing times for the electron pre-treatment (a few seconds), and generation of products that are well suited to downstream processing. Masterman points out, for example, that acid pre-treatment generally destroys most of the xylose contained in the biomass (about 40% of the total sugars) and produces toxic compounds, such as hydroxymethylfurfural (HMF), which inhibit downstream processing, including fermentation.

Whey coordinator Glanbia Ireland (Kilkenny; www.glanbiaireland.com), in collaboration with University College Dublin and Trinity College Dublin.

SOLVENT FILTRATION

Organic solvent nanofiltration typically involves polymer-based membranes that feature tiny pores, but form dense and amorphous networks. Well-ordered microporous materials, such as zeolites and metal-organic frameworks (MOFs), perform significantly better than these conventional membranes in various separation processes, but they are not suitable for extensive use in liquid separation because of their poor structural and chemical stability in liquids.

Now, researchers from King Abdullah University of Science and Technology (KAUST; Thuwai, Saudia Arabia; https://kaust.edu.sa) have developed a synthetic approach that produces well-ordered microporous materials that are stabilized by covalent keto–enamine linkages.

The new membranes, described in a recent issue of *J. Am. Chem. Soc.*, are said to outperform amorphous analogues and the best polymer-based systems. The organic solvent permeability of the new membranes is almost an order of magnitude higher than that of the best-reported polymer membranes, says KAUST. The membranes are said to be more stable than MOFs and more cost-effective than inorganic membranes. ❑

Making formaldehyde from methane, without generating CO_2

Researchers from South Korea have discovered a high-performance catalyst for the selective oxidation of methane to formaldehyde. The study was conducted by staff from Ulsan National Institute of Science and Technology (Ulsan; www.unist.ac.kr), Ajou University (Suwon; www.ajou.ac.kr) and Hanyang University (Seoul; www.hanyang.ac.kr), and led by Ulsan's professor Kwang-jin Ahn.

Methane is very stable and does not react easily with other substances. Temperatures above 600°C are required for a reaction that changes the chemical structure of methane. Vanadium oxide (V_2O_2) and molybdenum oxide (MoO_3) were known to be the best catalysts, but the conversion of methane to formaldehyde is low (less than 10%).

The catalyst developed by the Korean team has a core-shell structure consisting of vanadium oxide nanoparticles surrounded by a thin aluminum film. The shell protects the grain and keeps the catalyst stable and maintains stability and reactivity even at high temperatures. The team utilized hydrothermal synthesis followed by atomic layer deposition to prepare the catalyst based on the novel $SiO_2@V_2O_5@Al_2O_3$ core@shell nanostructures. The thickness of Al_2O_3 shells over $SiO_2@V_2O_5$ cores can be tuned by controlling the number of atomic layer deposition cycles.

With this catalyst the efficiency of conversion of methane to formaldehyde increased by more than 22%. Ahn says the team plans to further develop the catalyst manufacturing technology and the catalytic action in order to move to industrial application. ■

Business News

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Plant Watch

Sasol begins operating LLDPE unit at Lake Charles site

February 13, 2019 — Sasol Ltd. (Johannesburg, South Africa; www.sasol.co.za) announced that its new linear low-density polyethylene (LLDPE) unit in Lake Charles, La. has achieved beneficial operations. The LLDPE unit, which uses Univation Technologies' (Houston; www.univation.com) Unipol PE process to produce 470,000 metric tons per year (m.t./yr) of LLDPE, is one of two LLDPE plants at the site. The second, a 420,000-m.t./yr plant using process technology from ExxonMobil Corp. (Irving, Tex.; www.exxonmobil.com), is scheduled to come online later this year.

Arkema opens new polyester-resin manufacturing facility in India

February 13, 2019 — Arkema (Colombes, France; www.arkema.com) inaugurated a new polyester-resin manufacturing facility in Navi Mumbai, Maharashtra, India. This $15-million investment includes production capabilities for polyester powder resins marketed under the Reafree trade name. Arkema also produces Reafree resins and runs powder-coating laboratories at its facilities in Sant Celoni, Spain and North Kansas City, Mo.

Chemours triples low-GWP refrigerant production with startup of new plant

February 12, 2019 — The Chemours Co. (Wilmington, Del.; www.chemours.com) started up a new Opteon YF (HFO-1234yf) low global-warming-potential (GWP) refrigerant production facility at its Corpus Christi manufacturing plant in Ingleside, Tex. This $300-million facility will enable Chemours to triple the global capacity of its hydrofluoroolefin (HFO) 1234yf-based refrigerant products.

Sibur to expand polybutadiene rubber production capacity

February 12, 2019 — Sibur (Moscow; www.sibur.com) has launched an investment project aimed at enhancing polybutadiene rubber (Nd-BR) production at its Voronezh facility in Russia. A capacity ramp-up of 13,000 m.t./yr will increase total capacity to 48,000 m.t./yr. Currently, the project is in the design stage, with completion slated for 2021.

Praxair to double capacity at Missouri air-separation plant

February 11, 2019 — Praxair, Inc. (Danbury, Conn.; www.praxair.com) will expand production capacity at its Neosho, Mo. air-separation plant in response to the growing demand in Missouri and neighboring parts of Arkansas, Oklahoma and Kansas. The project is expected to be completed in 2020 and will double capacity at the Neosho facility.

Kemira to increase production of emulsion polymers at Alabama site

February 8, 2019 — Kemira Oyj (Helsinki, Finland; www.kemira.com) has announced a two-year investment of around €60 million to significantly increase production of high-molecular-weight emulsion polymers at its manufacturing site in Mobile, Ala. Construction is scheduled to begin in the first quarter of 2019 with full commercial operation starting in early 2021.

Saudi Aramco, Total and Daelim sign MOU to build new polyisobutylene plant

February 1, 2019 — Saudi Aramco (Dhahran, Saudi Arabia; www.saudiaramco.com), Total S.A. (Paris, France; www.total.com) and Daelim (Seoul, South Korea; www.daelim.co.kr) signed a memorandum of understanding (MOU) to build a new 80,000-m.t./yr polyisobutylene plant, which is expected to come onstream in 2024. The new petrochemicals facility, to be located in Saudi Arabia, will use feedstock from Saudi Aramco and Total's joint Amiral petrochemicals complex in Jubail.

Celanese to expand Clear Lake acetic acid plant

January 28, 2019 — Celanese Corp. (Dallas, Tex.; www.celanese.com) announced that its Clear Lake, Tex. acetic acid facility will be expanded from 1.3 million m.t./yr to around 2.0 million m.t./yr by late 2021. This project delivers rate flexibility and a platform that is expandable by an additional 600,000 m.t./yr.

BASF opens first phase of new antioxidants plant in Shanghai

January 25, 2019 — BASF SE (Ludwigshafen, Germany; www.basf.com) inaugurated a new antioxidants manufacturing plant at its Caojing site in Shanghai, China. With a capacity of 42,000 m.t./yr, the plant will produce antioxidants and associated forms and blends for the plastic-additives market.

Mergers & Acquisitions

Eni and Sabic to collaborate on new natural-gas conversion technology

February 8, 2019 — Eni S.p.A. (Rome, Italy; www.eni.com) and The Saudi Basic Industries Corp. (Sabic; Riyadh; www.sabic.com) agreed to jointly develop a technology for natural gas conversion into syngas that can be further transformed into high-value fuels and chemicals, such as methanol. The partnership will involve, among other activities, the construction of an industrial demonstration plant that will be built and operated inside one of Eni's industrial sites. This process was initially developed by Eni and was subsequently coupled with Sabic's short-contact-time reactor technologies.

De Nora acquires MIOX business from Johnson Matthey

February 7, 2019 — Industrie De Nora S.p.A. (De Nora; Milan, Italy; www.denora.com) has acquired the Albuquerque-based MIOX business from Johnson Matthey plc (London, U.K.; www.matthey.com) for an undisclosed price. MIOX specializes in proprietary mixed oxidants for onsite water purification, including electrochemical, disinfection, oxidation and filtration processes.

Ecolab to spin off Upstream Energy business segments

February 7, 2019 — Ecolab Inc. (St. Paul, Minn.; www.ecolab.com) plans to spin off its Upstream Energy business units as a standalone publicly traded company. The Upstream Energy business currently operates within Ecolab's Energy segment and consists of its oilfield chemicals production business and the WellChem drilling and well-completion chemistry business. Ecolab plans to retain the Downstream business, which serves petroleum refineries and petrochemical plants. The Upstream Energy business had 2018 sales of approximately $2.4 billion.

HollyFrontier completes acquisition of Sonneborn

February 7, 2019 — HollyFrontier Corp. (Dallas, Tex.; www.hollyfrontier.com) completed the previously announced acquisition of Sonneborn U.S. Holdings Inc. and Sonneborn Coöperatief U.A. for $655 million. Sonneborn is one of the world's largest dedicated suppliers of white oils, petrolatums and waxes, and operates manufacturing facilities in North America and Europe.

Chevron to acquire Pasadena refining assets from Petrobras

February 1, 2019 — Chevron Corp. (San Ramon, Calif.; www.chevron.com) signed a share-purchase agreement with Petrobras America Inc., a U.S.-based subsidiary of Petróleo Brasileiro S.A. (Petrobras; Rio de Janeiro, Brazil; www.petrobras.com.br), to acquire all shares and equity interests of Pasadena Refining System, Inc. (PSRI), including the 110,000-bbl/d petroleum refinery in Pasadena, Tex., and PRSI Trading, LLC, for $350 million. The acquisition will add to Chevron's refining network, which currently includes facilities in Pascagoula, Miss., El Segundo and Richmond, Calif. and Salt Lake City, Utah.

Cabot to divest its Specialty Fluids business for $135 million

January 31, 2019 — Cabot Corp. (Boston, Mass.; www.cabot-corp.com) has entered into a definitive agreement to sell its Specialty Fluids business to Sinomine (Hong Kong) Rare Metals Resources Co. in a transaction valued at $135 million. The transaction is expected to close in the third quarter of 2019 and is subject to customary closing conditions.

Kemira and Valmet partner on sludge and water treatment

January 23, 2019 — Kemira and Valmet Oyj (Espoo, Finland; www.valmet.com) have signed a partnership agreement to collaborate on water- and sludge-treatment applications. The agreement combines Kemira's chemistry and process optimization expertise with Valmet's analyzer and measurement technologies. ■

Mary Page Bailey

Chemical Recycling Makes Waste Plastic a Resource

With an eye toward a circular economy, technology developers are advancing a host of new approaches to chemical recycling of post-use commodity plastics

IN BRIEF

PET UPCYCLING

MAKING MIXED STREAMS WORK

PLASTICS FROM PYROLYSIS OILS

COORDINATED EFFORTS IN PLASTICS RECYCLING

Plastics are indispensable parts of almost every sector of the economy, with wide-ranging economic, environmental and convenience benefits in their use stage. But increasingly, the sheer volume of plastics produced (estimated at well over 300 million metric tons annually) presents environmental risks if the material is not captured, and represents a waste of resources if the material is disposed of in landfills. Currently, only a small fraction of commodity plastics are recycled globally (some estimates peg the number at 14%), while the majority end up in landfills, incinerators or in the environment, particularly the ocean.

The past two years have seen an acceleration and expansion of efforts aimed at addressing the issues associated with waste plastic. Stakeholders from several industries and from along the plastic value chain are involved in a host of plastic-waste initiatives (see box, p. 18). One aspect of the overall effort is to foster the idea that plastic waste can be a resource and that even single-use plastics have value after they are discarded.

Jeff Wooster, global sustainability director with Dow Packaging and Specialty Plastics (Midland, Mich.; www.dow.com), says "We are operating in a resource-constrained world, so we need to keep driving toward a circular economy. If plastics are landfilled, we lose their value. We put energy and resources into making those materials, and that is lost if we landfill the waste plastic. Recycling and energy recovery can retain the value of those materials for society."

The majority of plastic-recycling processes today are mechanical, where waste thermoplastic material from end-use products are melted and used as a component of another manufactured product. While improvements continue to be made in this area (for example, in spectral identification and sorting of plastic items), it is clear that mechanical recycling processes alone are not sufficient to handle the volume of plastic recycling that is required to shift society toward a circular economy with regard to plastic.

"Making meaningful progress on the problems we are facing related to plastic waste will take a truly global effort — it needs to be 'all hands on deck,'" says John Thayer, head of polyethylene business at NOVA Chemicals (Calgary, Canada, www.novachem.com).

The limitations of existing recycling processes and the push toward circular economy ideals has driven development of chemical recycling processes — those in which polymers are taken back to their monomers. This class of processes need to be developed and deployed at scale to complement existing mechanical recycling efforts. "Plastics are too valuable of a resource to end up as litter or trash," NOVA's Thayer comments. "One hundred percent of plastics should be reused, recycled or recovered and regenerated. We believe that chemical monomer recovery is the best long-term solution, where end-of-life plastics become feedstock that is chemically indistinguishable from fossil-fuel-sourced monomer."

Presented here are several advancements

in chemical recycling processes, including several technologies that have recently been, or are soon to be, scaled up.

PET upcycling

A sizeable amount of activity in the recycling field surrounds polyethylene terephthalate (PET), a widely used polyester that appears in many packaging and clothing applications, among others. Among the major commodity plastics, PET has the highest recycle rates (near 30%), although much of the PET waste that is recycled goes into lower-value materials.

"Some effective recycling processes exist for PET, but they require uniform streams of material, and generally result in products that are not likely to be recycled themselves," says Gihan Hewage, Lux Research Inc. (Boston, Mass.; www.luxresearchinc.com) analyst and co-author of a forthcoming report on waste products, entitled "Waste Conversion Innovations to Enable a Circular Economy." "There are now a number of companies developing technology for PET waste that allows a more circular path for PET, and that can result in products from recycled PET waste that are indistinguishable from petroleum-derived PET."

Among this group of companies is Loop Industries (Montreal, Canada; www.loopindustries.com). Loop has developed a technology that uses a catalytic process to convert low- or no-value waste PET and polyester fiber (plastic bottles and packaging, carpet and polyester textile of any color, transparency or condition and even ocean plastics that have been degraded by the sun and salt) into virgin-quality monoethylene glycol (MEG) and dimethyl terephthalate (DMT) for the manufacture of virgin-grade Loop-branded PET resin and polyester fiber.

In Loop's process, waste PET, which the company refers to as "feedstock," is introduced into a vessel at ambient temperature and pressure along with Loop's proprietary and patented catalyst and a carrier agent. The catalyst selects only the bonds between the polyester monomers, so it depolymerizes PET only, and leaves other plastics, such as polypropylene (PP) and high-density polyethylene (HDPE) intact, explains Nelson Switzer, Loop's chief growth officer. This means that Loop's technology can use low-value mixed streams of plastic and still yield virgin quality monomers. Because of this, the monomers can be separated easily from the process to produce food-grade quality Loop-branded PET. "Essentially, Loop's monomers become a drop-in substitute for petroleum-derived monomers," Switzer says.

Loop has established an industrial-scale pilot plant near Montreal, and is currently developing a full-scale commercial plant through a 50/50 joint venture with Indorama Ventures. Loop and Indorama are retrofitting an existing Indorama plant with the Loop technology to make Loop-branded PET resin. The commercial plant is expected to be operational in 2020. Loop also has an alliance with thyssenkrupp Indusrial Solutions to integrate the companies' technologies.

Switzer points out that there are many advantages of Loop's technology compared to conventional and mechanically recycled PET processes: notably the vast number of sources of PET and polyester fiber waste from up and down the PET value chain that can be used to produce Loop-branded PET. "We can use no-value or low-value PET waste that no one else wants," he says. While the company won't comment on costs, it says customers have agreed to its pricing.

Meanwhile, Carbios (Clermont-Limagne, France; www.carbios.fr) is taking a biological approach to depolymerizing PET. The company has developed a "biorecycling," process, where waste PET bottles and fibers are crushed and ground to powder, then placed in a bioreactor and heated to 65°C at atmospheric pressure. Specially bioengineered enzymes are added to de-polymerize, in less than 16 hours, the PET into monomers, MEG and PTA (purified terephthalic acid). Carbios has developed a proprietary filtration and purification process to generate

BioCellection

FIGURE 1. Several companies are developing chemical recycling approaches to handle low-value mixed plastics. Among them is BioCellection, whose founders are shown here inspecting mixed plastic waste that could be a feedstock for its process to make chemical intermediates from such plastic

high-purity monomers that can be re-polymerized by PET producers into high-quality PET with 100% recycled material.

The enzymes are extracted from naturally occurring bacteria that can break down PET, explains Carbios engineer Benjamin Audebert. "The enzymes have been engineered and optimized by our teams to be highly selective for PET, so only the PET is digested. In this way, the process can handle mixed-plastic streams," he says. Because PET is broken down selectively, other polymers are alone and can be separated. "The enzyme does the sorting for you," Audebert comments, "so you can use low-value mixed plastics materials as feedstock."

The enzyme's active sites cleave the ester bonds of PET. Carbios generated detailed models of the enzyme and its interaction with the polymer chains. The company will launch construction of a demonstration plant for this biorecycling technology in June 2019. It will be operational by the Q4 2020, Audebert says. Carbios will then license its technology for a commercial-scale facility to be fully operational by 2023. They are enlisting the help of the German division of Technip FMC, which has expertise in PET plants. Infinite recycling of PET is possible, Audebert comments. Carbios is working on enzymes for breaking down other polymers, and is also involved with technology for embedding specialized enzymes into single-use films of bio-based polylactic acid, so the plastic breaks down in an ecofriendly manner just after use.

In Switzerland, Gr3n Recycling (Lugano, Switzerland; www.gr3n-recycling.com) is also taking aim at PET, but instead of biological aids, they are using microwave technology to assist the depolymerization reactions of PET plastic into its constituent monomers. Gr3n's process uses a saponification reaction with sodium hydroxide in water to break down the polymer. The key innovation is the application of microwaves to the reaction to speed it up. "The microwaves act like a catalyst," says Mauricio Crippa, CEO of Gr3n. "The microwaves reduce the reaction times from multiple hours down to several minutes. Although the mechanistic details of how the microwaves catalyze the reaction at the molecular level are not clear, the process works on densified polyester fibers and on PET plastic.

The recycled waste is ground up and fed into a flow-through reactor, where the microwaves, generated by a standard magnetron, penetrate the mixture to aid the reaction and formation of MEG and PTA products. The company has built a demonstration-scale reactor and is currently building a demonstration plant in Italy that will process 1,000 ton/yr of PET feedstock. The demonstration plant will be completed at the end of 2019 or early 2020. The company's vision is to build plants close to cities to reduce the need to transport waste PET feedstock. It is going to partner with a mechanical recycler to handle the waste PET that is not used.

In yet another approach, Ioniqa Technologies (Eindhoven, the Netherlands; www.ioniqa.com) is using an iron-based ionic liquid in a proprietary technology that is able to convert any PET waste, including colored packaging, back into transparent virgin grade material. The technology has successfully passed its pilot stage and is now moving towards testing at an industrial scale.

Ioniqa, a spin-off business from the Eindhoven University of Technology, has formed a partnership with Unilever, and the largest global producer of PET resin, Indorama Ventures, to develop the new technology which converts PET waste back into virgin-grade material for use in food packaging. Ioniqa's Magnetic Smart Process is based on its proprietary Magnetic Fluid Catalyst (an iron-based ionic liquid). The platform technology is also being used in other applications beyond recycling.

In a process that was previously reported in this magazine (*Chem. Eng*., November 2016, p. 8 and August 2018, p. 5), the BCD Group (Cincinnati, Ohio; www.bcdinternational.com) developed a modified base-catalyzed decomposition process for removing dyes from PET fabrics, and separating cotton from cotton-polyester blend textiles and fabrics is now being applied to bottles made from PET.

Making mixed streams work

One of the most difficult problems in plastics recycling is multi-com-

Carbios

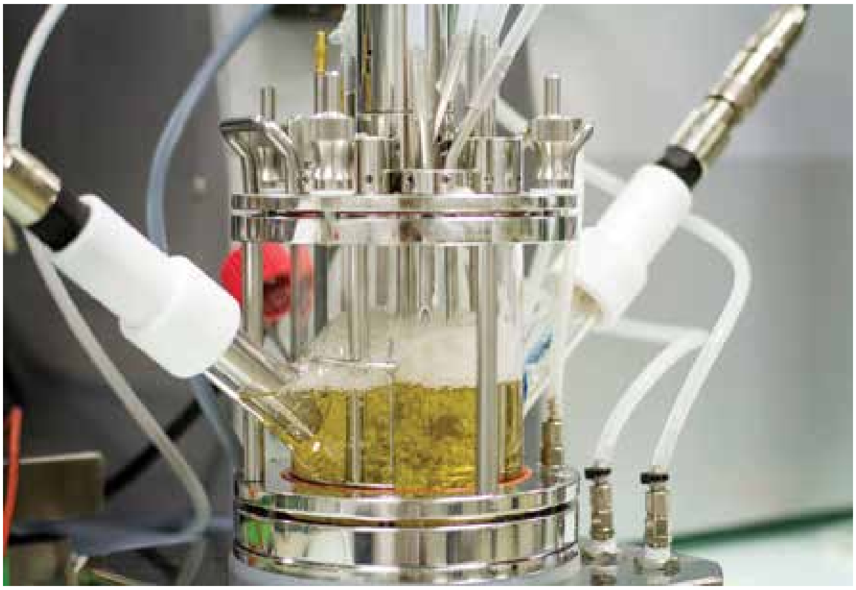


FIGURE 2. Carbios is developing an enzyme-based process to selectively de-polymerize PET from streams of mixed plastic waste in an effort to obtain high-purity monomers for new PET

ponent plastic packaging films. The use of these layered materials is widespread, and confers desirable functionality to the films in use. Examples are PE/PA, PE/PP, PE/PET. But the layering makes recycling the films after use problematic. A recently commercialized technology from APK AG (Merseburg, Germany; www.apk-ag.de) is aimed directly at this problem. The company's NewCycling technology allows the recycling of multi-layer flexible films in packaging applications.

"In commonly used mechanical recycling processes, multi-layer films end-up in many cases in incineration or are recycled to re-granulates with a quality just suitable for low-value applications, such as grass pavers or pallets," says Florian Riedl, director of business development at APK.

APK developed NewCycling as a way to separate the polymers in multilayer films so they can be used in applications normally for virgin-grade polymers. In NewCycling, the polymers are dissolved selectively by specially designed polymer-specific solvents. One component of the multi-layer film is dissolved while the other is left as a solid. Then the two components (solid of one species and liquid of another) are separated using a rotating system. The result of the process are sorted re-granulates (for example, PE and PA) with very high purity. The re-granulates are suitable to use them again in demanding applications, such as flexible packaging, Riedl says, so "we are offering an active contribution to the circular economy and help to achieve the growing recycling targets set by the industry and legislation."

The APK solvents are removed from the plastic polymer to levels below 1,000 parts per million, Riedl says, and the pure stream of polymer is then sent to an extruder, where it is pelletized for sale to makers of plastic films for packaging. The solvents are recovered for re-use in the process. One initial application will be for non-food-contact plastic pouches for laundry detergent, Riedl notes.

After developing the process at pilot scale for the past three years, APK has built its first commercial-scale production line for making plastic pellets from recycled multilayer films. The plant, located in Merseburg, Germany, began production of pellets last month. The plant is capable of producing 8,000 ton/yr of pellets from post-industrial waste (off-specification film material). APK is planning to build a second commercial plant to produce plastics from post-consumer waste

COORDINATED EFFORTS IN PLASTICS RECYCLING

The following are short descriptions of some selected consortia, alliances and collaborations that are aimed at various pieces of the plastics recycling movement.

Alliance to End Plastic Waste (AEPW; www.endplasticwaste.org). Launched in January 2019, AEPW is an alliance of nearly 30 global member companies from across the plastics and consumer goods value chain. The alliance has committed over $1.0 billion, with the goal of investing $1.5 billion over the next five years to help end plastic waste in the environment. The Alliance will develop and bring to scale solutions that will minimize and manage plastic waste and promote solutions for used plastics by helping to enable a circular economy, according to AEPW. Member companies include BASF, Braskem, Chevron Phillips Chemicals, Clariant, Covestro, LyondellBasell, NOVA Chemicals, Sasol, Total, Veolia and others.

Materials Recovery for the Future (MRFF; www.materialsrecoveryforthefuture.com). MRFF was formed by the non-profit arm of the American Chemistry Council (ACC) to foster the addition of flexible plastic packaging to the recycling stream. MRFF is trying to install sorters that can separate flexible packaging from recycled streams, so that consumers can include flexible packaging into their regular recycling bins. Members include the Dow Chemical Co., PepsiCo, SC Johnson, Nestle, the Association of Plastics Recyclers, Target Stores and others.

CEFLEX (www.ceflex.eu) CEFLEX is the collaborative project of a European consortium of companies representing the entire value chain of flexible packaging and continues the work of Project REFLEX and Project FIACE.

Recycle Across America (RAA; www.recycleacrossamerica.org). RAA created the world's first and only society-wide standardized labeling system for recycling bins to make it easier for people to participate in recycling programs. The standardized labels are proven to help increase recycling levels and significantly decrease the costly garbage thrown in recycling bins, RAA says.

Project STOP (Stop Ocean Plastics; www.systemiq.earth) is a frontline initiative to prevent ocean plastic leakage in Southeast Asia. Its partners include Borealis, SYSTEMIQ, the Government of Norway, NOVA Chemicals, Borouge and Veolia and Nestlé.

in the form of mixed films fractions from recycling sorting centers.

In another approach aimed at recycling waste plastic that is not currently recycled, BioCellection Inc. (Menlo Park, Calif.; www.biocellection.com) has developed a novel catalytic process that can break down PE into dicarboxylic acids, which can then be used as intermediates to synthesize other chemicals. The proprietary process is designed to work on PE films that are generally not being recycled currently, explains Erik Freer, BioCellection chief technology officer.

The overall process designed by the company effectively recovers and recycles the catalyst, using mild temperatures and pressures to keep costs low. “The raw-materials costs for our process are much lower than existing processes for making dicarboxylic acids,” Freer says, so it is a good way to create a high-value chemical intermediate from waste plastic.

After a bench-scale demonstration, the company built a pre-pilot unit that is an order of magnitude larger than the bench-scale system to validate the effectiveness of the catalyst. They are now designing a commercial pilot plant that integrates all the components of the process and aims to validate the complete process, Freer says. In 2018, the company won a $100,000 award from UCLA and the Anthony and Jeanne Pritzker Foundation for emerging environmental projects.

Products from pyrolysis oil

One approach to addressing the problems associated with recycling mixed-stream plastics is to break down the plastics via thermochemical means, such as pyrolysis (thermal decomposition in the absence of oxygen), then separate them into fractions, similar to the refining of crude oil. The wax/oil mix from plastic can then be fed to steam crackers to be made into olefins for plastic production. A number of companies are operating in this area, including Cynar (Ireland), Recycling Technologies Inc. (U.K.), Plastic Energy Ltd. (U.K.) and Recenso GmbH (Germany). The outlets for this material are expanding as the companies are partnering with others who can use the products from the pyrolyzed plastic.

One example of this is BASF SE’s (Ludwigshafen, Germany; www.basf.com) ChemCycling project. In late 2018, BASF announced the first pilot products made from oils derived from the thermochemical decomposition of recycled plastic waste for which no recycling solutions currently exist. Using oils from plastic waste generated by partner Recenso, BASF put the material into its steam cracker at Ludwigshafen to make ethylene and propylene. From these olefins, BASF made plastic packaging for mozzarella cheese, for example.

Another similar arrangement was recently established by Plastic Energy Ltd. (London, U.K.; www.plasticenergy.com), which has developed a process for making a raw material feedstock from mixed plastics known as Tacoil. Tacoil results from the recycling of low-quality, mixed plastic waste otherwise destined for incineration or landfill. The upgraded pyrolysis oil will yield a cracker feedstock with similar characteristics and quality as the fossil-based naphtha feedstock, the company says. The naphtha cracking process yields the same monomers, such as ethylene and propylene, that are used to manufacture low-density polyethylene (LDPE), high-density polyethylene (HDPE) and polypropylene (PP).

A partnership between Plastic Energy and SABIC (Riyadh, Saudi Arabia; www.sabic.com) was recently announced where SABIC is building a facility in Geleen, the Netherlands to make plastics out of Tacoil. At the recent World Economic Forum in Davos, Switzerland, SABIC announced that the line of certified circular polymers made from Tacoil will be used by key SABIC customers Unilever, Vinventions and Walki Group for packaging solutions for a variety of consumer packaging in the food, beverage, personal- and home-care markets. Those products will be introduced into the market this year. The plant in Geleen is anticipated to enter commercial production in 2021. ■

Scott Jenkins

Editor's note: For more information about plastics recycling supply chains and recyling hurdles, see the online version of this article at www.chemengonline.com.

Flow Monitoring for Today's Chemical Processes

New technologies provide diagnostics and calibration verification to improve maintenance and process efficiency

IN BRIEF

PROPER METER SELECTION

HIGH-VALUE PRODUCTS AND SAFETY

WORKFORCE AND DIAGNOSTICS

Because many processes in the chemical process industries (CPI) are controlled by flow, it is important that the technology selected for flow monitoring and measurement is not only suitable for the application, but also able to withstand harsh environments and demanding conditions. Due to the high value of the materials being processed, it's also imperative that the technology provides the necessary level of accuracy and repeatability. In addition, loss of knowledge and other workforce challenges currently being experienced in industry necessitate that instruments provide diagnostics and other helpful features.

"So many processes in the chemical industry rely upon flow to ensure the right amount of material comes in at the right time for a chemical reaction to properly occur. Choosing the wrong instrument or one with poor accuracy in the application could amount to failure of process or cause unacceptable product loss, resulting in lost revenue," says Michael Bequette, vice president of engineering with SOR (Lenexa, Kan.; www.sorinc.com). "Therefore, the technology has to be appropriate for the application. Further, flow instrumentation that offers measurement verification and/or diagnostics is trending now because these features help increase accuracy, reduce costs and simplify maintenance."

Proper meter selection

According to Bequette, selection of the right meter for the application, paying attention to installation practices and knowing your specific process conditions and challenges are key to achieving the most accurate flow-monitoring system. "The first step is pairing the right technology with the process," he says. "If a magmeter is installed in a fluid that's not conductive, the meter simply isn't going to work. The technology has to be appropriate for the application. Beyond that, you want to pay particular attention to the installation practices, because you can purchase the right technology but if you don't ensure proper installation, you may receive an inaccurate flowrate, no matter the accuracy of the selected meter."

SOR

FIGURE 1: The SOR T21 Thermal Differential Flow Switch can be used for difficult applications, such as upset conditions that normally are running at a very low flowrate to a very high flowrate

In other words, different conditions may impact the accuracy of the meter. For example, vibration will render ultrasonic or Coriolis meter measurements inaccurate, but if the flowmeter is placed in a location where the piping doesn't have much vibration or if dampeners are attached to the pipe to prevent vibration, the reading will be more accurate. "There are a lot of techniques that can be employed when designing the system, but processors have to be aware of how different operating conditions can impact different technologies and their accuracy and proceed accordingly," says Bequette.

It's also important to know the specific challenges of the process environment and how they may affect accuracy of the flow measurement. "There are quite a few challenges in the chemical processing industry, including contamination buildup in the lines,

Schneider Electric

FIGURE 2. Schneider Electric's CFT51 Coriolis flowmeter can handle two-phase flows, such as gas and liquid, with accuracy in a chemical process

Fluid Components International

FIGURE 3. FCI's ST100 Series thermal mass flowmeters offer an embedded no-cost dry method and a true wet method in-situ calibration verification

high temperatures, corrosive materials, material phase changes, bubbles and dynamic ranges," explains Bequette. "So it's important to know the specific challenges in your process and select the technology that can best address them."

For example, he says dynamic ranges are common in many applications. "You may be measuring a flowrate on a flare stack, but then, all of a sudden, you have an upset condition and the flowrate is twenty times what you typically experience and, depending on the technology used, that flowmeter may not be able to adequately detect very low or very high flow conditions." Bequette notes that thermal dispersion technology might be the right choice for applications that experience dynamic ranges (Figure 1).

In other processes, multi-phase

Endress+Hauser

FIGURE 4. Endress+Hauser's Promass Q Coriolis flowmeter features on-board diagnostics and Heartbeat Technology to ensure product and process safety

flow may be an issue, says Wade Mattar, flow marketing manager with Schneider Electric (formerly Foxboro; Foxboro, Mass.; www.schneider-electric.us). "Often they may have liquid and gas mixed in a line — a challenging application — and this may create bubbles in the flow, which further adds to the difficulty in achieving an accurate measurement," he says. "For these difficult conditions, it's important to select a technology, such as a Coriolis meter, that can handle them with accuracy" (Figure 2).

Mattar continues: "Processors often don't realize that one size does not fit all when it comes to flow measurement. That's why there is a variety of flowmeter types; each one is designed for a specific type of application and to handle specific process challenges. Selecting the right one for the application and environment will help ensure a more accurate reading."

High-value products and safety

Accurate readings are a necessity in today's CPI. "Manufacturers of flow equipment need to ensure that meters and instruments are accurate, because chemical processors are usually working with large quantities of valuable materials and they want to be able to accurately control and monitor them to avoid losses," explains Adam Booth, product marketing manager — flow with Endress+Hauser (E+H; Greenwood, Ind.; www.us.endress.com).

Schneider Electric's Mattar agrees: "Accuracy is king in the chemical industry where they are constantly blending streams of different chemicals in very precise percentages, batching recipes for a high-quality final product or transferring product into containers or unloading tank trucks. On top of that, there may be regulatory involvement in the mix and the equipment may be audited to ensure it is accurate."

A.W. Lake

FIGURE 5. A.W. Lake's FAC sensors are equipped with Bluetooth connectivity, allowing them to send diagnostic and other information to mobile devices

Safety, adds SOR's Bequette, is another area of concern for flowmeter accuracy. "If the flowmeter is not accurate and there is a chemical coming in for a reaction, poor accuracy could result in an unstable reaction," he says. Cooling water is another example. If enough cooling water isn't introduced due to an inaccurate flowrate, runaway temperatures, and the hazards associated with those conditions, could result.

Unfortunately, at the same time as the need for greater accuracy is increasing, industry is also going through a period of workforce challenges, including retirement, attrition and associated loss of knowledge, which have led to fewer, less experienced workers taking on more responsibilities. How does this affect flow monitoring accuracy? Accuracy of readings requires calibration verification, and this is a notoriously labor-intensive and costly task, requiring scheduled maintenance. Further, drift may occur prior to scheduled maintenance. When this happens, unless there are experienced operators or maintenance technicians who realize something is "off," there may be costly product loss or quality issues, or hazardous situations can occur.

Workforce and diagnostics

"Industry is currently struggling with a loss of expertise due to retirement and attrition and losing these experienced people not only limits the knowledge of the rest of the plant, but it puts stress on the workers who are left because they don't have the history to know how to address the root cause of the problem," says Mike Klein, vice president of chemical industry marketing with Emerson Automation Solutions (St. Louis, Mo.; www.emerson.com). "Another result is that fewer people are working the plant, so the workload is higher for those who remain. For these reasons, it is imperative that the devices provide trustworthy, accurate and reliable data that really allow the users to have a good decision-making process."

To assist, providers of flow measurement devices are working to provide instruments that offer helpful features, such calibration verification and diagnostic capabilities.

"There is a lot of innovation at the flowmeter level in making the meters more reliable and accurate because a measurement a user doesn't trust is a useless measurement," says Schneider Electric's Mattar. "So the current trend includes providing on-board verification of accuracy and health of the measurement."

For instance, in its Coriolis meters, Schneider Electric offers flowmeter verification technology that alerts users if the instrument has varied from its as-built performance. "Users can check on a scheduled frequency from the instrument itself whether the device is still working as designed," explains Matter.

Before such capabilities, the only way to verify a flowmeter was to remove it from the process and send it out to have the calibration verified. Randall Brown, director of marketing with Fluid Components International (FCI; San Marcos, Calif.; www.fluidcomponents.com) says verification technology, such as FCI's Veri-Cal, provides several benefits (Figure 3). "Having a built-in, in-situ check that can be performed on demand or on a timed basis allows users to verify that the instrument is still as accurate as when it was shipped from the factory," he says. "The big benefit here is that they don't have to pull it out of the process, replace it with a spare

and send it back to the factory to have the calibration verified. That procedure was very labor intensive, time consuming and costly and resulted in downtime. And, often users discovered that the device was still within calibration! So, there is an obvious time and cost savings associated with in-situ verification capabilities."

Likewise, E+H has self-diagnostics, called Heartbeat, built into its meters. "The devices are constantly monitoring their own health and have a verification aspect," says Booth. "A user can start a verification on demand and the meter will check the sensor and check the associated electronics, and when the verification report is complete, provide a PDF report showing what it tested and whether the device passed or failed."

Howard Siew, industry manager — chemical, with E+H adds: "Heartbeat technology also enables users to trend data so they will be able to recognize if there is corrosion, erosion or build up and plan for maintenance before there is an issue" (Figure 4).

"This level of intelligence, coupled with realtime and in-process measurements, allows users to get more insight out of the instruments and allows the instrument to be viewed as a window into the process, giving users the ability to plan out a maintenance schedule or determine how often the device should be pulled out for cleaning to minimize unplanned shutdowns," continues Nathan Hedrick, national product manager — flow, with E+H.

Often, this intelligence is coupled with applications (apps) that are accessed via Bluetooth to provide information from remote locations, says Robert Childs, strategic account manager with A.W. Lake (Oak Creek, Wis.; www.aw-lake.com). "With Bluetooth connectivity and a mobile app, this type of diagnostic information can be displayed in the palm of the users hand via their phone or tablet. Set up of the instrument can also be performed from the mobile device instead of on the face of the unit," he says. "It can also be arranged so that reminders regarding calibration and maintenance schedules can be sent through the app to the user" (Figure 5).

Emerson's Klein agrees: "This is where you really start to see the industrial internet of things (IIoT) and digitalization come into play. The latest versions of electronics provide more functionality because they are able to send out more than just the primary variable and then send it to a central management system that can identify the device's health over time. And, if it's tied into an app, such as Emerson's Insight, the platform can give users ideas about the root cause of any problems."

This means, instead of an engineer having to look at variables and trend and graph them, the software in the app does the work for them and suggests that the issue could be, for example, two-phase flow and then offers suggestions on how to remedy the situation.

"Using devices that are rich in diagnostics not only for the device, but also for the process, not only allows processors to perform maintenance in a predictive way versus preventive, but also helps alleviate the workplace challenges, such as less experienced workers, they are currently experiencing," says Klein. ■

Joy LePree

Focus on Air Pollution Control

GEA

Bionomic Industries

LumaSense Technologies

These ceramic filters have catalysts built-in

The BisCat filter system (photo) combines the three process stages of de-dusting, separation of acid components and reduction of total hydrocarbons and oxides of nitrogen (NOx) in one unit. The system uses high-temperature filters with ceramic elements that enable the removal of NOx, dioxins, mercury and volatile organic compounds (VOCs) through an integrated catalyst matrix. BisCat ceramic catalyst filters are chemically inert and corrosion-resistant. Particle separation takes place with the aid of filter elements made of mineral fibers. These ceramic candles are well proven and very flexible to use, even with regard to modifications of operating parameters, especially at high gas temperatures. No cooling of fluegases is required and no thermal energy is wasted. Filter elements are cleaned of separated dust online during operation by means of separate, compressed-air-jet pulses. The single or multi-sectional housings allow a maximum filter length of 6 m. This means that even large gas-volume flows can be cleaned. By injecting lime-based reagents, inorganic pollutants, such as HF, HCl and SOx, can also be absorbed. Applications include the cement and glass industries, incinerators, refineries and roasters. — *GEA, Düsseldorf, Germany*
www.gea.com

New wet electrostatic precipitator for control of fines

In January, this company launched its new HEI (high-energy ionizer) Wet Electrostatic Precipitator (WESP) system (photo). Said to be a breakthrough in the advancement of state-of-the-art fine-particulate-matter control, the HEI WESP System incorporates a unique discharge electrode technology that can be sized to specific applications, and concentrates a high-intensity ionizing corona in strategic areas within the collecting tubes instead of distributing it along the entire length of the tubes' treatment area. The resultant particle charging fields are two to three times stronger than conventional precipitators and deliver higher particulate charges, higher migration velocities and a smaller precipitator size for gas capacities from 1,000 through 300,000 actual cubic feet per minute (acfm), says the manufacturer. Unlike other precipitators that utilize sprays, overflow weirs or packed marble beds, the HEI WESP incorporates the Ultimix Conditioning System for gas saturation and collection-tube cleaning and the patented RotaBed Pre-Scrubber for acid removal and particulate-loading reduction. Typical applications include submicron particulate-matter scrubbing, aerosols, mists and smoke removal. — *Bionomic Industries, Inc., Mahwah, N.J.*
www.bionomicind.com

Continuous monitoring of pilot flames and flared gases

The E2T Quasar 2 series of instruments (photo) is designed for continuous-duty monitoring of pilot flame and flared gases from flares. The base system provides low-cost basic flare-pilot monitoring capabilities. The advanced model has an intensity milliampere (mA) output that allows for a setpoint mA level to be set in a user's distributed control system (DCS) for both the pilot and flaring status signals from the same unit. Additional add-on features are available for a configurable product to meet a wide range of flare types, monitoring requirements and budget. Two models are available: Quasar 2 M8100-EXP and Quasar 2 M8100-EXP Advanced. Scalable options are available with the advanced version and include continuous 4–20 mA, peak hold and decay, and power supply with 85 to 265 V a.c. input. — *LumaSense Technologies, Inc., Santa Clara, Calif.*
www.lumasenseinc.com

Flowmeters with CEMS and CERMS capabilities

Engineers responsible for reporting stack gas emissions data to federal, state or local authorities will ap-

Note: For more information, circle the 3-digit number on p. 82, or use the website designation.

preciate the optional continuous emissions monitoring system (CEMS) and continuous emissions rate monitoring system (CERMS) applications package available with the MT100 Series multipoint thermal mass flowmeters (photo). When specified with the optional CEMS and CERMS applications package, the MT100 Series flowmeters meet the requirements of the U.S. Environmental Protection Agency's (EPA) 40 CFR Part 60 and 40 CFR Part 75. This package provides a 24-h interval automated calibration drift test of low and high span points, and interference sensor check. The optional CEMS applications package includes both an automated and on-demand self-checking of calibration drift and sensor interference. The results of the CEMS tests are presented as a simple pass or fail message on the LCD readout. — *Fluid Components International (FCI), San Marcos, Calif.*
www.fluidcomponents.com

Fluid Components International

A methane detector for monitoring landfill emissions

Q.E.D Environmental Systems

The new Landtec SEM5000 methane detector is suitable for landfill surface emissions monitoring (SEM). The SEM5000 meets or exceeds U.S. Environmental Protection Agency (EPA) Method 21, Determination of Volatile Organic Compound Leaks, requirements for quarterly SEM monitoring. Unlike flame ionization devices (FIDs), the SEM5000 uses a patented laser technology, so there is no cross-gas effect or false readings due to the presence of other gases or hydrocarbons as with FIDs. No flame is required, which is a huge benefit for sampling in a potentially explosive environment. No external gas bottle is required for operation, and the technology is accurate down to 0.7 parts per million (ppm). — *Q.E.D. Environmental Systems, Inc., Dexter, Mich.*
www.qedenv.com

A portable emissions monitor for compliance testing

The E8500 PLUS emissions analyzer (photo) is a complete, portable tool for EPA-compliance level emissions monitor-

E Instruments International

ing and testing. The E8500 PLUS is ideal for regulatory and maintenance use in boiler, burner, engine, turbine, furnace and other combustion applications. The unit features an internal thermoelectric chiller with automatic condensate removal and an optional sample-conditioning unit to minimize NOx loss from condensation. The device can be customized for up to nine gas sensors, including electrochemical sensors (for O_2, CO, NO, NO_2, SO_2 and H_2S) and non-dispersive infrared sensors (for CO_2, hydrocarbons and high CO levels). — *E Instruments International, LLC, Langhorne, Pa.*
www.e-inst.com

Seals that significantly reduce methane emissions

This company recently launched its latest gas-seal technology designed to be retrofitted into centrifugal compressors with oil seals to significantly lower operating costs, improve reliability and reduce methane emissions by up to 95%. The Aura 120 Narrow Section gas seal

John Crane

(photo) enables the company's latest gas-seal technology to be fitted into a larger percentage of older equipment, bringing with it the benefits of non-contacting design. Gas-seal technology eliminates the need for oil lubrication associated with contacting seals and the resulting need to address harmful emissions entrapped in the oil. — *John Crane, Chicago, Ill.*
www.johncrane.com

Wet scrubbers tailored to each plant's application

Despite the recent relaxation of certain EPA standards, state and local municipalities often set their own requirements that meet or exceed these federally regulated minimums. As the cost of non-compliance increases and certain regulations become more stringent, it can be a challenge to meet emission requirements. This co mpany designs and supplies wet scrubbing technologies tailored to a plant's needs and built to users' exacting specifications. The line of jet venturis, high-energy units and packed towers are able to offer high removal efficiencies while being optimized for minimal utility consumption. Systems can be built to handle a wide range of pollutants, including acid gases, SOx, NOx, ethylene oxide, VOCs and even odor control. — *CR Clean Air Group, LLC, Parsippany, N.J.*
www.crcleanair.com

Gerald Ondrey

New Products

These compressors are designed to reduce energy use

The new SM 7.5, SM 10, SM 15, and SFC 8 rotary-screw compressors (photo) have been redesigned to reduce energy consumption, extend service life and improve operational performance. These models feature the new Sigma 06 airend, which is said to increase intake capacity when combined with IE4 motors on the 10- and 15-hp models to deliver up to 10% more flow than previous versions. The updated compressors also include a dual-flow fan combined with an external-facing cooler, resulting in approach temperatures as low as 7°F. This improves the effectiveness of downstream dryers and filters in removing contaminants that impact product quality and tool life. The die-cast, sickle-shaped blade of the dual-flow fan reduces noise and cools both the drive motor and the interior of the machine for greater reliability. A built-in web server and communication ports enable remote monitoring. The SFC 8 model features a separate drive cabinet with dedicated cooling to protect the frequency converter and maintain optimal operating temperatures. To reduce floor space and installation time, these models are also available with integrated dryers. — *Kaeser Compressors, Inc., Fredericksburg, Va.*
www.us.kaeser.com

Simplify screen changing for separator systems

The Electro-Lift system (photo) assists in expediting change times for separator screens, eliminating the need for two people to remove each frame. Electro-Lift is mounted independently to the frame so there is no need for it to be locked out when working. This also enables easier access to the separator unit's interior for inspection and cleaning. Engineered with a 120-V sealed, gear-driven system, the system is simply plugged into an electrical outlet and only requires a single switch for operation. Unlike traditional hydraulic or pneumatic changing systems, the frames will not fall if the power goes out during screen changes, according to the company. Electro-Lift systems are adaptable to fit a variety of different frame-deck configurations, and most makes and models of round separators can easily convert to this system. — *Midwestern Industries, Inc., Massillon, Ohio*
www.midwesternind.com

A three-in-one biogas-measurement device

The MGP261 (photo) is said to be the world's first multigas measurement instrument for in-situ monitoring of methane, carbon dioxide and humidity, offering realtime gas composition data without sample extraction or treatment. This compact measurement instrument is Ex certified up to Zone 0, which enables inline installation in explosive atmospheres. The MGP261 gives continuous readings of methane, carbon dioxide and water vapor directly in process pipelines. It is optimized for biogas production processes, such as anaerobic digestion of waste from agriculture, industries and municipalities, as well as the utilization of landfill gas. The MGP261 is based on this company's patented Carbocap technology for infrared gas measurement. — *Vaisala Oyj, Helsinki, Finland*
www.vaisala.com

Monitor CFATS compliance with this new software module

This company's Compliance Manager software module aids chemical processors in assuring that their sites are compliant with the U.S. Department of Homeland Security's Chemical Facility Anti-Terrorism Standards (CFATS). This module is said to be the first commercial relational-database software application designed specifically to track CFATS compliance solutions and security measures. The module is flexible, scalable and secure, and provides consistent data management in real time, allowing users to manage all of their security protocols in one place. In addition, the Compliance Manager CFATS module allows organizations to submit and track forms and reports related to various requirements, and it also identifies and organizes the 18 CFATS Risk-Based Performance Standards with a company's compliance activities. As site security plans

Kaeser Compressors

Midwestern Industries

Vaisala

or alternative security-program data are entered, the software offers continuous, one-step documentation and tracking of required annual audit information. — *Telgian Management Technologies, LLC, a subsidiary of Telgian Holdings, Inc., Phoenix, Ariz.*
www.telgian.com

Kelvion Holding

This new heat exchanger makes use of exhaust gases

The new Exhaust Gas Heat Exchanger (EGHE; photo) transfers heat produced by exhaust gases from combustion engines to a liquid. When heated up, this liquid can be used in cogeneration plants, combined heat and power plants, heating systems, biogas plants and furnaces. Its compact design makes the EGHE well suited for processes where space is limited. Made from high-alloyed stainless steel, the EGHE can handle temperatures up to 550°C. Its sturdy design withstands high continuous stress caused by vibration and pressure pulsation. The EGHE is equipped with a compact finned-heat-exchanger module, which is easily replaceable and service-friendly. Compact fin-tube bundles, which are completely made out of stainless steel, are insensitive to soiling and easy to clean with high pressure and cleaning agents. — *Kelvion Holding GmbH, Bochum, Germany*
www.kelvion.com

Electro-Chemical Devices

These versatile wastewater samplers are portable

The AQUA Series of portable wastewater samplers (photo) consists of three models designed to meet a wide range of sampling requirements. The very small AQUA-Compact, the passively-cooled AQUA-Coolbox and the multi-bottle AQUA-Multix provide plant technicians with comprehensive sampling flexibility. The AQUA-Compact is useful when samples need to be pulled and transported between sites or for temporary compliance purposes. The insulated AQUA-Coolbox ensures samples are stored at a cool temperature for proper laboratory analysis. The AQUA-Multix features a quick "lift-off" design for bottle exchange. AQUA Series samplers are equipped with an advanced air-pump vacuum sampling system, which delivers an accurate, reliable, representative and repeatable sample. As with stationary samplers, the AQUA samplers support the extraction of samples from either non-pressurized or pressurized effluent-pipe sources. — *Electro-Chemical Devices (ECD), Anaheim, Calif.*
www.ecdi.com

Charles Ross & Son

This mixer is designed for hot melts and viscous dispersions

The Model CDA-800 multi-shaft mixer (photo) has a special triple-shaft design specifically suited for hot melts and viscous dispersions. The CDA-800 has a mixing capacity of 500–800 gal and is designed for full-vacuum operation (29.5 in. Hg). The mixer is suitable for high-temperature operation up to 600°F and includes an insulated 50-psig stainless-steel dimpled jacket covering the side and bottom of the dished-bottom mixing can. The removable mix vessel sits 24 in. above the floor for convenient discharge. Speed, time, temperature and vacuum level are displayed on a 10-in. touchscreen and controlled via a programmable logic controller (PLC). — *Charles Ross & Son Co., Hauppauge, N.Y.*
www.mixers.com

Proco Products

Use this mobile app to optimize penetration-seal selection

This company has launched a new mobile application (app) to aid engineers in the proper selection and installation of pipe-penetration seals (pen-seals). Pen-seals can achieve a cost-effective mechanical seal when piping must pass through walls, floors, tanks, pipeline castings or vaults. The Pen-Seal Calculator (photo) is designed to assist in selecting the correct number of links and the correct size of links for pipe penetrations passing through walls or floors. To achieve a 100% water- or gas-tight seal, users can enter the pipe outer diameter and the penetration inner diameter to provide the required size and link combination. The Pen-Seal Calculator app is available for Android and Apple devices. — *Proco Products, Inc., Stockton, Calif.*
www.procoproducts.com ■

Mary Page Bailey

Hygienic Process Equipment Fabrication

Department Editor: Scott Jenkins

In hygienic process operations, proper system construction and fabrication has the greatest influence on end-product quality and the success of process validation. Even well-designed hygienic systems can be compromised by leaching, poor internal finishes and mishandled material sourcing and other fabrication issues. All can lead to contamination and bacterial growth in the system. This one-page reference provides information on key quality-assurance procedures for the fabrication and assembly of hygienic systems that will help prevent contamination and bacteria growth during operation.

Contamination can come from unlikely sources, such as process media reacting with rubber over time, causing carbon to be extracted from rubber parts. Pipes can have improper finishes or poor welds, creating safe harbors for bacteria to grow. Following proper procedures can minimize potential issues.

Setup considerations

The following are considerations for each stage of the hygienic process build, from sourcing to assembly.

Parts and materials purchasing. From raw metal suppliers to shop welders, materials must be handled properly, and procedures should create individual responsibilities for verifying proper handling at every step. Important information includes the source of the metal materials and what requirements those materials need to meet. Determine what documentation (for example, proof of chemical composition) is needed from each supplier and conduct a review of the orders to verify that they meet the requirements for materials of construction.

Material handling. During sourcing of process components, it is important to know how equipment parts and materials are handled and shipped from the supplier. For example, what do parts touch during shipping and how are they handled during receiving? Once the parts arrive, there should also be an organized way to identify parts at the facility. Also, a procedure is needed to verify the mill test report (MTR) review, logging and tracking. What are the conditions under which parts are stored and who is responsible?

Fabrication and assembly. A procedure should be in place to approve parts and materials for use, as well as to ensure that parts are fabricated, welded and tested correctly. A third-party Level-2 certified welding inspector (CWI) should inspecting welds in the process equipment.

TABLE 1. EXAMPLE HYGIENIC FABRICATION QUALITY AUDIT

Activity / inspection and test required	Responsible department
Verify that all tubing, piping, fittings and valves are capped, except when being used in fabrication	Quality control (QC)
Storage area is clean and free of contaminants	Engineering / QC
Pipe and fittings are segregated by material type, size, surface finish and so on	Receiving/Eng./ QC
Stainless-steel, aluminum and high-alloy piping is covered and off the ground	Rec./Eng./ QC
Material and parts are staged and stored with protection in assigned area	Rec./Eng./ QC
Verify forklift forks, hooks and straps are protected against cross-contamination	QC
Verify fabricators, welders, welding operators or inspection personnel are wearing clean, white cotton, lint-free or latex gloves when around interior product surfaces or unwelded joints on impact piping	QC
Verify gas certifications received and displayed on stainless dewar cylinders	QC
Weld sample board made and kept in fabrication area	Eng./QC
Verify lint-free wipes are of desired brand	Eng./QC
Verify marking pens are “white low-chloride marker” for use on stainless steel	Eng./QC
Verify that tables used in fabrication are protected agaist cross-contamination	Eng./QC
Verify that high-purity argon (99.999%) is available for shielding and purge, and is stored in stainless-steel dewars with test report attached from supplier	Eng./QC
Verify argon hoses for welding equipment and purging are plastic (not rubber)	Eng./QC
Verify tools are color coded for hygenic stainless steel use only	QC
Verify material and parts are being cleaned with denatured alcohol and lint-free wipes	QC
Verify project work area is clean and orderly. Ensure that tools are put away and fabrication area is cleaned at the end of each day	SF/ QC
Verify that post-weld shielding and purge gas is greater than 30 seconds	QC

Source: EPIC Quality Assurance team

Fabrication quality audit

Conducting a fabrication quality audit can help ensure that necessary quality assurance activities are completed according to the correct procedures. An example audit list, showing activities, inspections and tests, is presented in Table 1. Proper storage methods are included for verification. Also, the standards (not shown here) against which the activities should be verified are listed next to each item with a personal sign-off to verify proper procedures have been followed throughout. Validation sheets matching each procedure ensures the process was followed and documented. The following are areas that would be covered by hygienic quality assurance audit:

Weld documentation. This includes the welder's name, when the weld was performed, and what materials were used. Also included is which weld procedure was performed and whether it was the proper procedure. Other questions include: how much oxygen was used during the welding? Who inspected the weld and when?

Assembly documentation. This includes, for example, the type of gaskets used, documentation showing where they were used and the date installed, as well as an audit of all joints, verifying that the correct gaskets are present and correctly installed.

Proper fabrication validation. As an example, hygienic systems are designed to eliminate dead legs during fabrication. Questions that should be asked include the following: is everything on the assembled system properly sloped? Were pockets created during fabrication? Did all piping get processed to the correct internal finish? Which requirement are you verifying against? ■

Editor's note: Content for this column was provided by Jeff Koenigs, principal project manager and professional engineer, EPIC Process Systems (www.epicmodularprocess.com)

Calcium Carbide Production from Limestone

By Intratec Solutions

Calcium carbide is the most industrially relevant carbide because of its important role as the basis of the acetylene industry. In locations where there is a shortage of petroleum, calcium carbide is used as the starting material for the production of acetylene, which, in turn, can be used as a building block for a range of organic chemicals, such as vinyl acetate, acetaldehyde and acetic acid.

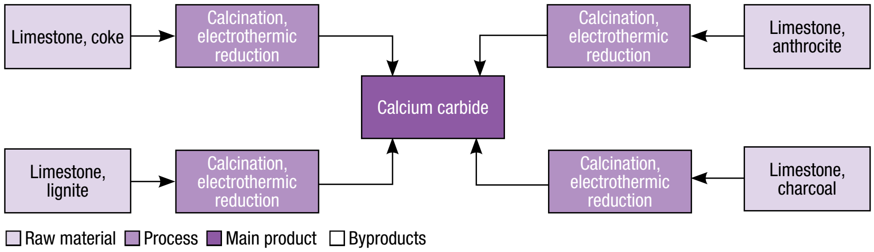


FIGURE 2. Several production pathways exist for calcium carbide, depending on the carbon source

The process

The following describes a process for calcium carbide production from limestone and coke (Figure 1).

Feed preparation. Initially, coke is dried with hot air in a tray dryer to reduce moisture in the coke. After drying, the coke is transferred to the electric furnace. Limestone is crushed in a jaw crusher into a uniform particle-size range. Some gross impurities originating from the limestone are separated in a screener.

Lime kiln. The crushed limestone is calcined in a vertical-shaft lime kiln. The calcium carbonate present in the limestone is decomposed into calcium oxide (CaO, or lime) and carbon dioxide, which is used to preheat the limestone feed. The resulting CaO is passed through a screener for the removal of gross impurities. Then the CaO is conveyed, along with dry coke, to an electric furnace, which contains electrodes through which high current passes to provide heat.

Electric furnace. The lime-coke mixture flows down the furnace until reaching the high-temperature reaction zone, where molten CaO reacts with coke and generates molten calcium carbide. The reaction zone is a packed bed of coke, where empty space is filled with molten calcium carbide and gaseous byproduct carbon monoxide. The CO gas from the electric furnace is fed to a water scrubber for removal of any residual particles. The gas is then temporarily stored in a gas holder before it is fed through a blower to the dryer and the lime kiln upstream, where it is used as fuel.

The molten calcium carbide product is removed from the furnace by means of continuous tapping, and it falls into a water-cooled cylinder, where the products solidifies.

Finishing. The solid calcium carbide is transferred to the carbide crusher, where it is sieved and crushed until it reaches the desired particle size for the final product. The crushed product is screened to remove impurities and then conveyed to silos that feed the packing section.

Other production pathways

Calcium carbide production consists of the reaction of CaO (obtained from limestone) with a carbon material. There are several different routes to manufacturing, related to the different sources of carbon (Figure 2).

Economic performance

The total operating cost (raw materials, utilities, fixed costs and depreciation costs) estimated to produce calcium carbide was about $1,000 per ton of calcium carbide in the first quarter of 2015. The analysis was based on a plant constructed in the U.S. with the capacity to produce 80,000 metric tons per year of calcium carbide.

This column is based on "Calcium Carbide Production from Limestone – Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/calcium-carbide-production-cost. ■

Edited by Scott Jenkins

Editor's note: The content for this column is supplied by Intratec Solutions LLC (Houston; www.intratec.us) and edited by Chemical Engineering. The analyses and models presented are prepared on the basis of publicly available and non-confidential information. The content represents the opinions of Intratec only. More information about the methodology for preparing analysis can be found, along with terms of use, at www.intratec.us/che.

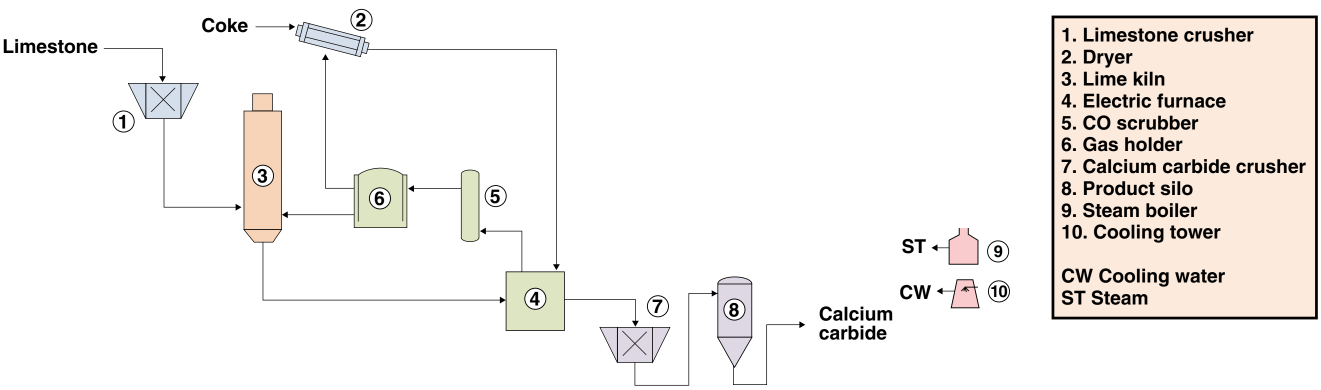


FIGURE 1. The process diagram shown here outlines a process for the production of calcium carbide from limestone

Part 1

Non-Destructive Testing: Managing Corrosion Under Insulation

Corrosion under insulation (CUI) creates a pervasive and versatile challenge to the integrity of insulated equipment, but non-destructive inspection can help to avoid undesirable CUI surprises

Ana Benz, Fadi Basma and Michael Townsend
IRISNDT

IN BRIEF

RISK-BASED INSPECTION

GENERAL NDE SELECTION

DIGITAL TECHNOLOGIES

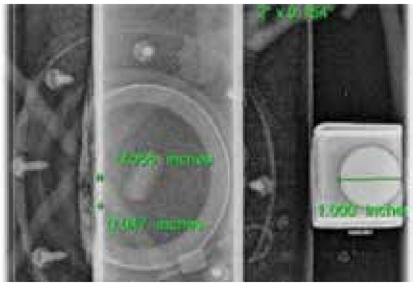
FIGURE 1. This horizontal, coated 0.375-in.-thick pipe leaked due to CUI after only four years of service

Corrosion under insulation (CUI) has been occurring ever since industry started insulating equipment. However, most of the CUI reported until the 1970s developed in stainless steel due to stress-corrosion cracking. At that time, with limited insulation, carbon-steel equipment did not develop significant CUI [*1*]. Since then, with higher energy costs, carbon-steel piping, tanks and vessels have been more intensively insulated to save on energy costs, and as a result, they have begun to develop CUI.

CUI is a common problem for petroleum refineries, petrochemical facilities, power plants and chemical and fertilizer plants. One's predisposition could be to consider CUI as a problem that is isolated only to sites in close proximity to a marine environment, but this is not always the case. CUI can happen in dry industrial sites as far away from the sea as the Canadian prairies (Figure 1). Once equipment is insulated, the proximity to cooling towers, leaking heat tracing, rain, mist from melting snow that saturates insulation and other leaks or steam can have an impact on CUI.

CUI can remain undetected until a leak develops or until the insulation and clad-

FIGURE 2. This pipe with a corrosion-monitoring location (CML) showed minimal losses near the CML (left). Approximately 2.5 ft below the CML (below), the NPS 2 pipe had experienced losses from 0.055 to 0.154 in. Computed radiography inspection (right) confirmed the presence and severity of this corrosion



ding or jacketing are removed or damaged, making CUI exceedingly challenging to find (Figure 2). Earlier reports stated that one single nondestructive examination (NDE) could not be used to identify CUI [2]. This remains the case today as engineers combine several NDE techniques to perform CUI assessments. In such assessments, corrosion rates are usually presented in mils per year (mpy), where one mil is equal to 1/1,000 of an inch. The techniques and strategies now used are summarized throughout this article, and several images are provided to illustrate CUI in piping and tanks and the detection methods applied in industry today.

Risk-based inspection

Prior to performing NDE, a facility needing CUI inspections must have a thorough understanding of its CUI history. This helps to select the circuits or equipment on which the inspections should concentrate. Inspection for CUI should be considered for insulated pressure vessels and piping in intermittent service or when operating temperatures fall within the known and accepted ranges for CUI occurrence for the material in use. The facility's staff must determine probability and consequence of failure in order to establish the magnitude and scope of inspection that will be required. The facility must also determine which

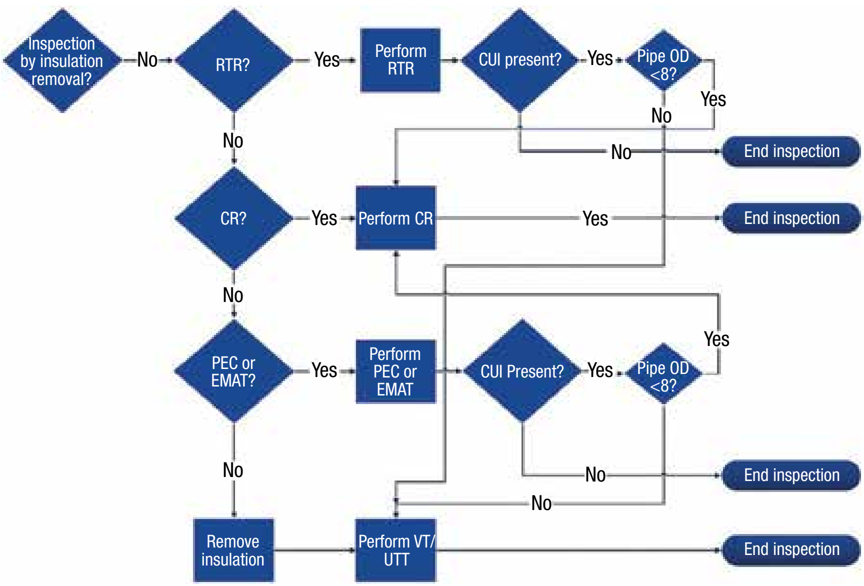


FIGURE 3. This project flowchart illustrates considerations for ferrous piping NDE selection, including realtime radiography (RTR), computed radiography (CR), pulsed eddy-current method (PEC), electromagnetic acoustic testing (EMAT), ultrasonic thickness testing (UTT) and visual testing (VT)

FIGURE 4. Realtime radiography (RTR) is performed on piping to show the degree of CUI damage that has occurred

codes or practices will be used to determine and define that scope. These could include, but are not limited to, the following standards developed by the National Association of Corrosion Engineers International (NACE; Houston; www.nace.org) and the American Petroleum Institute (API; Washington, D.C.; www.api.org):

1. NACE SP0198 [*3*] details the variables to consider. A key variable is the potential source of water ingress, including: rainfall; drift from cooling towers; condensate falling from cold service equipment; steam discharge; process liquids spillage; spray from fire sprinklers; deluge systems and washdowns; leaking heat tracing; groundwater; and condensation on cold surfaces after vapor-barrier damage
2. API 571 Section 4.3.2.3 [*4*] lists the following critical factors:

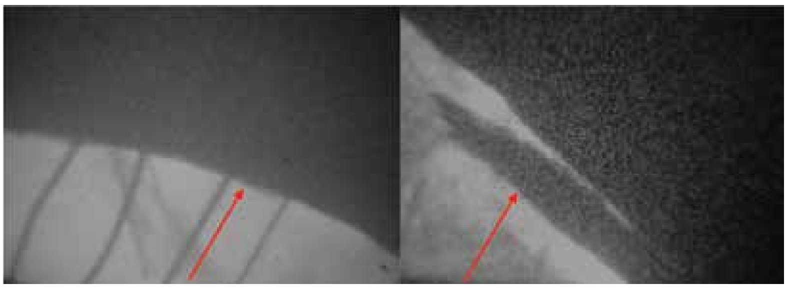
- The physical location (industrial, marine or rural); moisture (humidity), particularly designs that trap moisture or when present in a cooling tower mist; temperature; and the presence of salts, sulfur compounds and soil
- Marine environments, which can be very corrosive (20 mpy), as are industrial environments that contain acids or sulfur compounds that can form acids (5–10 mpy)
- Inland locations exposed to a moderate amount of precipitation or humidity, which are considered moderately corrosive environments (around 1–3 mpy)
- Dry rural environments, which usually have very low corrosion rates (less than 1 mpy)
- Designs that trap water or moisture in crevices that are more prone to attack
- Operating temperatures up to around 250ºF (121ºC) experience increased corrosion rates. Above 250ºF, surfaces are usually too dry for corrosion to occur except under insulation (see Section 4.3.3 of API 571)

With all this information, walkdowns can commence. Site and NDE personnel will benefit from meticulously planning around the access points and techniques to be used line by line and component by component. Choosing how many locations per line should have spot NDE is important. Using modern digital technologies, the walkdown information, the static equipment information and drawings can all be pre-loaded for NDE personnel to develop reports with acceptance and rejection comments as soon as the NDE is completed in the field in real time.

General NDE selection

To minimize, if not eliminate, insulation removal, realtime radiography (RTR) is a commonly used pre-screening examination. After the RTR results, digital or computed radiographic (CR) testing is commonly performed

FIGURE 5. RTR Images show minimal OD corrosion (left) and significant OD corrosion (right)



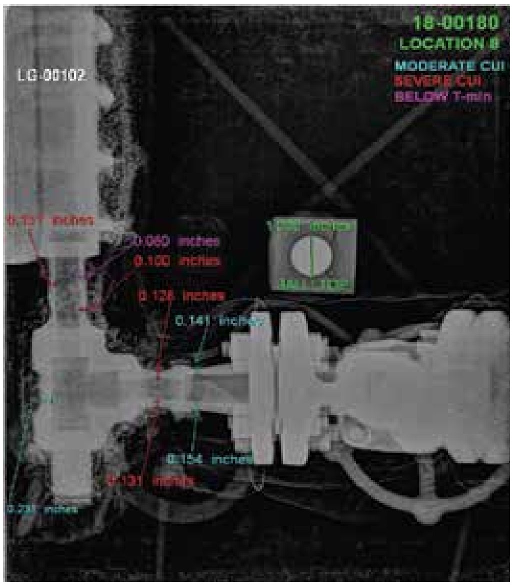


FIGURE 6. Computed radiography (CR) imagery is the preferred method for visualizing CUI damage to smaller-diameter pipes

on lines of NPS 8 and smaller. Nominal Pipe Size (NPS) is a North American set of standard sizes for pipes used for high or low pressures and temperatures. “Nominal” refers to pipe in non-specific terms and identifies the diameter of the hole with a non-dimensional number, loosely based on the inner diameter (ID) of the pipe in inches. The flowchart in Figure 3 illustrates a common NDE selection process for examining piping for CUI [*5*].

Realtime radiography (RTR). Realtime radiography (RTR) is also called fluoroscopy [*6*]. Inspection personnel view the silhouette of the pipe or vessel outer diameter (OD) on a monitor as the location is inspected (Figure 4). Corrosion products form buildups on top of the OD. Due to size limitations, this technique is used more often on piping rather than vessels. The technique is defined by its radiation source and image intensifier or detector. It does not require film. RTR results in images such as those shown in Figure 5. The maximum opening of the arms on the equipment determines the largest diameter of the equipment and insulation that can be inspected. This has changed with time and will likely continue to do so.

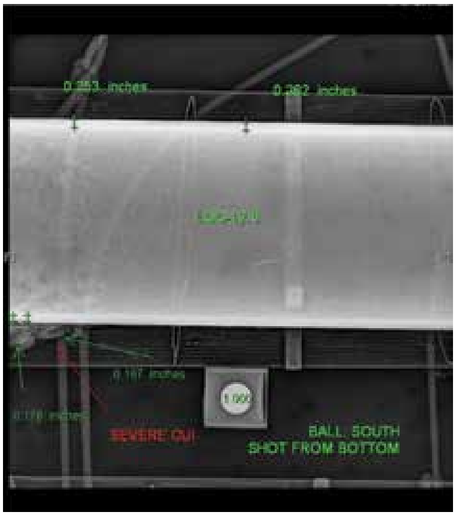


FIGURE 7. Digital detector array (DDA) radiography images are a quick way to obtain inspection data

Profile radiography with film; with computed radiography (CR); and with digital detector array (DDA) radiography. Profile radiography (also referred to as a shadow shot), as its name implies, refers to a profile view

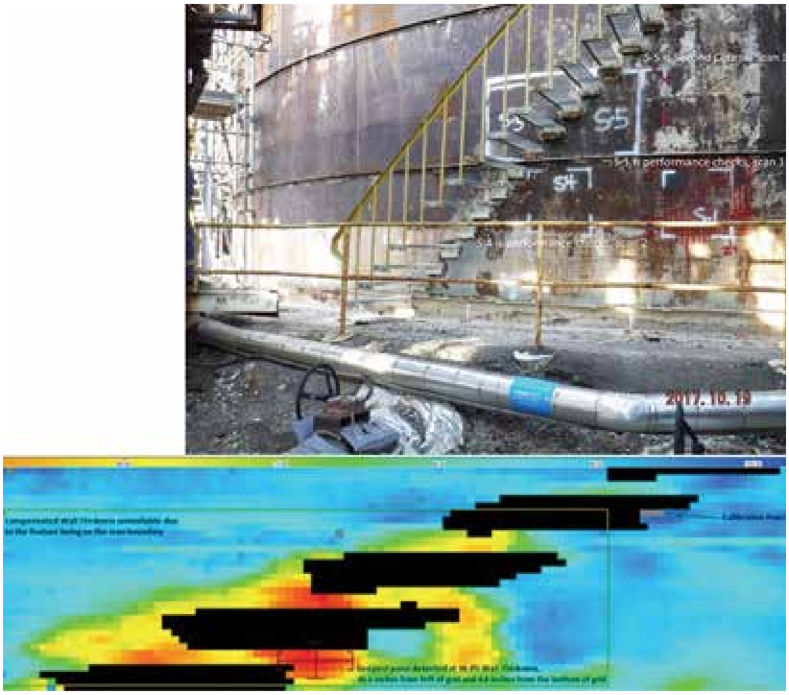


FIGURE 8. A tank with heavy deposits is shown on the top image. The lower image shows a pulsed eddy-current inspection that was performed without removing the deposits. The inspection identified that the areas beneath ladder rungs experienced the greatest losses

of the wall thickness. Profile radiography has been used to measure wall thickness values since the 1950s [7]. Today, it typically follows RTR for piping of NPS 8 and smaller.

With the advent of CR and DDA, profile radiography is the technology of choice for inspecting smaller-diameter piping (Figure 6). Though occasionally, film radiography is used in CUI studies, CR and DDA have largely displaced traditional profile radiography with film. With these techniques:

- The piping is typically exposed to gamma rays from an Iridium-192, Selenium-75 or Cobalt-60 gamma source. This point is common with traditional radiography with film
- The remaining thickness can be assessed along pipe edges
- Shorter exposures are needed to obtain images than for traditional radiography with film
- Digital radiographs and images can be stored and shared quickly

FIGURE 9. A guided-wave testing (GWT) transducer ring is placed on insulated piping to screen for potential CUI damage

- Multiple insulated components of various diameters and with some thickness variations can be viewed in one radiograph

CR requires imaging cassettes to be placed in a laser reader, where they are scanned to obtain a digital image. DDA images develop directly on the detector and need not be processed in a reader. They are obtained in significantly less time than CR (seconds versus minutes). They also require less radiation than is needed for radiography with traditional film and for CR. On the other hand, durability of the cassettes and other factors are more favorable for CR than for DDA (Figure 7).

Pulsed eddy-current (PEC) method. For CUI examinations, PEC (Figure 8) is often used in piping with NPS 8 or greater. This method is also used when inspecting vessels for CUI, because this allows for a decrease in insulation removal. A PEC probe scans the insulated equipment and identifies general (averaged) losses, but isolated pits can be difficult to detect. The detection sensitivity of this electromagnetic inspection technology depends on the footprint of the probe, liftoff or insulation thickness and on the steel thickness [2]. As with other electromagnetic techniques, edges (for example, nozzles, flanges or the end of a structure) pose a challenge for inspection.

Guided wave testing (GWT). GWT, an ultrasonic inspection method (Figures 9 and 10), can be used to screen for potential CUI damage in piping. The inspection is performed with minimal insulation removal, and it has been used in piping with asbestos insulation. A special tool (transducer ring) is clamped around the pipe that transmits guided waves in both directions along the pipe. Reflected signals from defects and pipe features, such as welds, are received by the transducer ring and sent to the main unit. The tested sections must be carefully selected, since the length inspected in one scan is limited by the number of elbows, fittings or welded shoes. Losses due to corrosion must be greater than 4 to 10% of the pipe cross-section to be detectable [2].

Ultrasonic thickness measurement. In CUI studies, direct ultrasonic thickness measurements can be made on pressure equipment with diameters larger than NPS 1 where the insulation has been removed or in locations with insulation plugs. Since removing insulation is expensive, these inspections are not performed routinely during CUI pre-screening.

Thermal or infrared imaging examination. Using this technique, one aims to identify where the insulation is wet as opposed to dry. Based on thermal or infrared imaging, a heat picture of the surface is obtained. This technique detects areas where the insulation has been breached; it is not used during surveys where remaining thickness values are needed. Once the insulation is dry, the suspect area is not flagged.

Neutron backscatter examination. This technique uses a radioactive source to identify wet insulation. It does not assess remaining thickness and has specific applications, such as screening for locations where stress-corrosion cracking can develop. Once the insulation is dry, the suspect area is not flagged.

Other NDE techniques. NDE technologies are evolving rapidly and those less commonly used have not been described in this article. Updates on applications of the technologies are often available from the American Society for Nondestructive Testing (Columbus, Ohio; www.asnt.org), NACE International, API and in journals such as *Inspectioneering*.

FIGURE 10. Here, GWT was used to identify CUI pits

Rope access services. This innovative technology is a backbone for today's CUI programs. Specialized harnesses and ropes are used to reach difficult-to-access areas safely and with minimum process disruptions. An inspection project comprising more than 1,400 piping circuits [*4*] was completed using rope access, aerial work platforms and existing scaffolding. Rope access was used for NDE and to refurbish damaged insulation and piping (Figure 11). Without rope access, the cost and time needed to complete the project would have been prohibitive.

FIGURE 11. Rope access is a modern method for inspecting and refurbishing insulation in difficult-to-access areas

Digital technologies

Today's digital information is a backbone for CUI projects. Digital information is available to all key personnel in these projects — the equipment owner, the inspection crew and management personnel — while the projects progress. The findings and reports provide the most revealing images of equipment damage that have been available to date. The prompt communication allows for technical and cost-control discrepancies to be addressed and managed promptly.

Digitalization and other modern advances in NDE allow engineers to look into the integrity of insulated equipment with minimal insulation removal. Rope access allows us not only to inspect, but also to refurbish insulated equipment within affordable times and budgets. Digital technologies for NDE and for reporting, such as intrinsically safe tablets, allow prompt communications that were not possible a decade ago. Nevertheless, multiple NDE techniques are still needed to assess CUI. As well, detailed planning prior to inspection allows for effective and efficient CUI inspection projects

Inspecting for CUI is necessary, since moisture finds its way into insulation via many mechanisms, leading to sometimes severe damage, as illustrated in the photos shown in this article. There is certainly more than meets the eye when considering the challenges of CUI. CUI damage is full of surprises, but the NDE guidelines described here should help engineers to better tackle the always-changing CUI environment at their facilities. ■

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References

1. Delahunt, J.F., Corrosion Under Thermal Insulation and Fireproofing, an Overview, Paper No. 03022, NACE Corrosion Conference, 2003.
2. Fitzgerald, B.J., Lazar, P., Kay, R.M., Winnik, S., Strategies to Prevent Corrosion Under Insulation in Petrochemical Industry Piping, Paper 03029, NACE Corrosion Conference, 2003.
3. NACE SP0198, Control of Corrosion Under Thermal Insulation and Fireproofing Materials — A Systems Approach, 2017.
4. API 571 Section 4.3, Damage Mechanisms Affecting Fixed Equipment in the Refining Industry, 2nd Ed., April 2011.
5. Nichols, M.O., Townsend, M., Partnering to Zero in on Corrosion Under Insulation with NDE and In-Touch Software, RMC-18-Paper #RMC-18-240, 2018 AFPM Reliability & Maintenance Conference.
6. API Recommended Practice (RP) 583, Corrosion Under Insulation and Fireproofing, 1st Ed., May 2014.
7. Hecht, A., Bauer, R., On-Line Radiographic Wall Thickness-Measurement of Insulated Piping in the Chemical and Petrochemical Industry, ECNDT Conference Paper, May 1998.

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Part 2

Using Corrosion as a Process Variable

Monitoring and analyzing historical corrosion data can provide insights not available from manual inspection and measurement techniques

Jake Davies
Emerson Automation Solutions

IN BRIEF

A VERY COMPLEX CHARACTERISTIC

MEASURING AND MONITORING METAL LOSS

THE VARIABILITY OF METAL LOSS

A CASE IN POINT

REAL-WORLD LESSONS LEARNED

FIGURE 1. Unique corrosion issues can arise when petroleum refiners swap feedstocks

Some petroleum refiners looking for ways to improve profitability have lately turned to buying opportunity crudes from secondary sources. These crudes, while priced less than more premium feedstocks, often contain various contaminants, including solids and corrosive compounds. Such contaminants can damage processing equipment by corroding and eroding it from the inside out (Figure 1). In the worst case, a pipe wall may become progressively thinner over time until the pressure causes it to break open — hot hydrocarbons that are perhaps higher than the auto-ignition temperature can escape and mix with air, resulting in a potentially serious safety and environmental incident.

This is an extreme case, but not without precedent in the global petroleum refining industry. Opportunity crudes pres-

ent unique challenges and they often have vastly different characteristics than the crudes many petroleum refineries are designed to handle. The feedstock may be more or less corrosive than the last batch, or corrosive in a different way, meaning that the corrosion risk to the inside of the process equipment is varying continuously.

For plant operators, corrosiveness has to be viewed as another process variable — it has to be measured and managed. However, in the past, there was little instrumentation available to characterize it and measure the impact that the corrosiveness of the process fluids has on process equipment. Fortunately, this situation is improving with the advent of more advanced corrosion-monitoring technologies, including wireless systems.

FIGURE 2. Non-intrusive wireless sensors monitor pipe wall thickness in real time and send data to the plant automation system via a wireless mesh network

A very complex characteristic

The interaction of chemicals and metals has been studied extensively, and the mechanisms of metal loss and weakening are very complex. Countless articles and books have been written on the topic, but for this discussion, and to most operators in the real world, the question is straightforward: Is this process fluid eating away at my plant's pipe walls, and if so, at what rate?

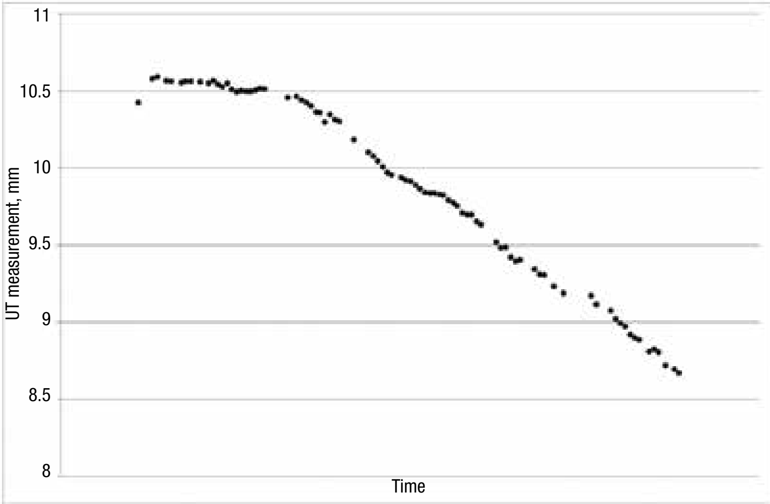


FIGURE 3. Ultrasonic-thickness (UT) measurement data can be collected and historized for analysis, just like any other process variable

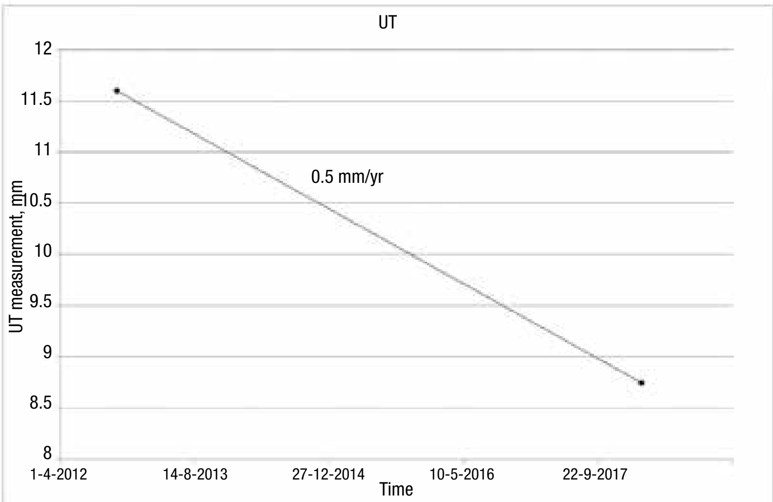
The answer depends on the nature of the corrosive components of the process fluid, the operating parameters, such as flowrate or temperature, and the metallurgy of the pipe and vessel walls. Obviously, the metallurgy is fixed for all practical purposes, but in most facilities, it is not consistent across different areas and process units. There can be a variety of alloys used in different areas that have been installed at different times, and in varying states of health, with respect to pipe thickness.

Plant operators can work at forestalling the effects of corrosion in a variety of ways, including the following:

- Employing a corrosion allowance that recognizes the inevitability of metal loss and compensates by simply using thicker pipe sections in strategic areas.
- Establishing safe operating windows to slow the deterioration process. For example, operators may have concluded that metal loss with a specific grade of crude oil increases significantly beyond a specific temperature, so the process is adjusted to remain below the threshold. Obviously, this requires a great deal of knowledge about the characteristics of the crude and its interaction with the alloys, and it assumes the process will still work effectively at the adjusted parameters. Typically, the integrity operating window is set using theoretical concepts, which do not necessarily reflect reality.
- Material upgrades are a very effective approach. Replacing carbon-steel pipe with an appropriate stainless grade can extend its life, but it is very costly and cannot be done easily while a unit is running. If the next turnaround is not for another several years, a different approach will be necessary.
- Corrosion inhibitors can be quite helpful, but again, these have to be matched with the characteristics of the process fluid and the metallurgy to be effective. The additive designed for the crude or process fluid being handled currently might not work with what is slated for next week. It also adds cost, potentially offsetting the reason for running the opportunity crude in the first place.
- Inspections make sense, and can warn of impending problems if carried out correctly. However, they can be difficult to perform, since the operator must access specific points. Checking an elbow where there is no catwalk near the top of a tower that is clad in insulation is not an easy task. Moreover, manual inspections using a handheld ultrasonic measuring device do not have very high repeatability — remaining within ±1 mm is doing well in most facilities. Furthermore, the need to access each location every time a measurement is desired means that, in practice, measurements are only taken every few years, which is not frequent enough to detect major corrosion events in many cases.

There is one strategy that can help make all of these activities more effective, and it begins with treating corrosion as a process variable.

FIGURE 4. When wall-thickness measurements are made manually, there are often too few data points to provide useful statistical analysis



Measuring and monitoring metal loss

Process units in a petroleum refinery typically have hundreds and even thousands of process instruments measuring temperature, flow, pressure, level and other attributes. Operators can watch the readings in real time, and these readings are usually recorded in a historian system, so it is possible to see what a specific value was at a

specific time in the past. This is valuable information in trying to figure out the causes of upsets and improving overall efficiency. Corrosion, quantified as actual metal loss measured in mils (one mil is equal to 1/1,000 of an inch) or micrometers (μm), can be treated the same way.

Wireless wall-thickness measurement sensors (Figure 2) can be installed throughout a unit on pipe and vessel walls to monitor metal thickness continuously. Data from these sensors can be transmitted over a wireless network to automation systems and process historians. Engineers can use these data to make decisions in real time, and the data can also be historized (Figure 3), just like data from a temperature or pressure transmitter or sensor, and retrieved for analysis.

The ability to watch metal loss over time can provide even deeper insight into the process, and assist with other corrosion-mitigation strategies

Just as a pressure transmitter can warn when the equipment has exceeded a safe value, a thickness monitor can trigger an alarm when wall thickness has reached a safety threshold. This is an important function, but the ability to watch metal loss over time can provide even deeper insight into the process, and assist with other corrosion-mitigation strategies.

The variability of metal loss

With years of data collected using continuous wall-thickness monitoring in many facilities, one point has emerged time and again: metal loss is not a linear process. Experience has shown how it is common to see 80% of the metal loss during 20% of the time, or even 90% in 10% of the time. This accelerated metal loss happens when the corrosive elements really dig into the metal due to the presence of particularly aggressive corrosive elements that are unaffected by the inhibitors in use.

Metal loss is not a fast process, so observing it requires time and precision. Permanently mounted wireless ultrasonic-thickness sensors can achieve a repeatability of 10 μm, which is the equivalent of 0.000394 in., so it is possible to detect very small changes over time. It is also possible to identify the variability in the rate of loss, a major improvement as compared to infrequent periodic inspections.

A hypothetical example. A well-trained inspector has taken two readings, one year apart, at exactly the same place with a handheld ultrasonic thickness-measuring device. Assuming that the device has a higher degree

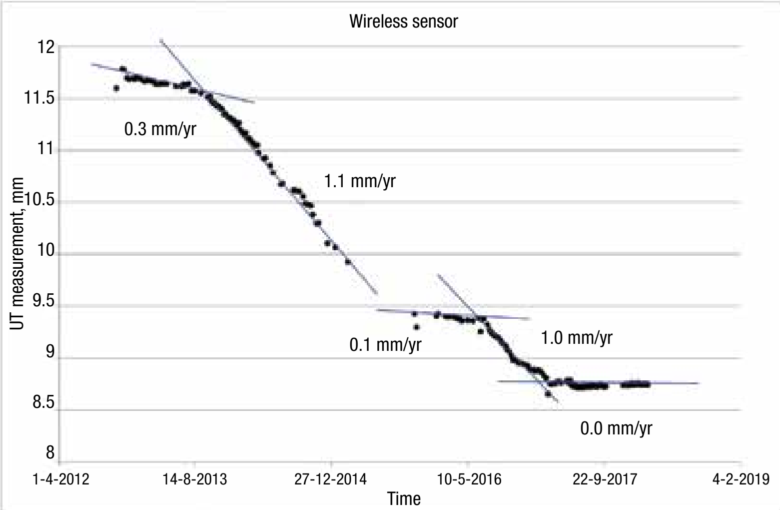


FIGURE 5. When wall-thickness data points are provided continuously, it becomes clear that metal loss is not a linear process

of accuracy than is likely possible in real life, the readings show a 1-mm reduction of wall thickness over that time period, indicating fairly aggressive corrosion. The conclusion based on two data points will suggest a more-or-less straight-line change (Figure 4) over the year. Looking at the same measurement point logged with a continuous monitor will far more likely show a jagged curve (Figure 5), where there are periods of rapid loss interspersed with times of very little change.

Corrosion happens at highly variable rates because there are so many variable factors at play. Some of the factors are controlled — for example, the injection rate of a corrosion inhibitor or the operating temperature of a reactor — and others are not, such as the specific corrosion profiles that are brought into the process by the feedstock.

Trying to diagnose and solve the problem when there are very few data points is effectively impossible. Intrusive corrosion probes capable of giving an indication of the corrosiveness of the fluid and test coupons have their value, but they do not, on their own, deliver the most important measurement: actual metal loss, or lack thereof, in real time.

A case in point

The corrosion picture for a petroleum refinery is hugely complex, and some facilities

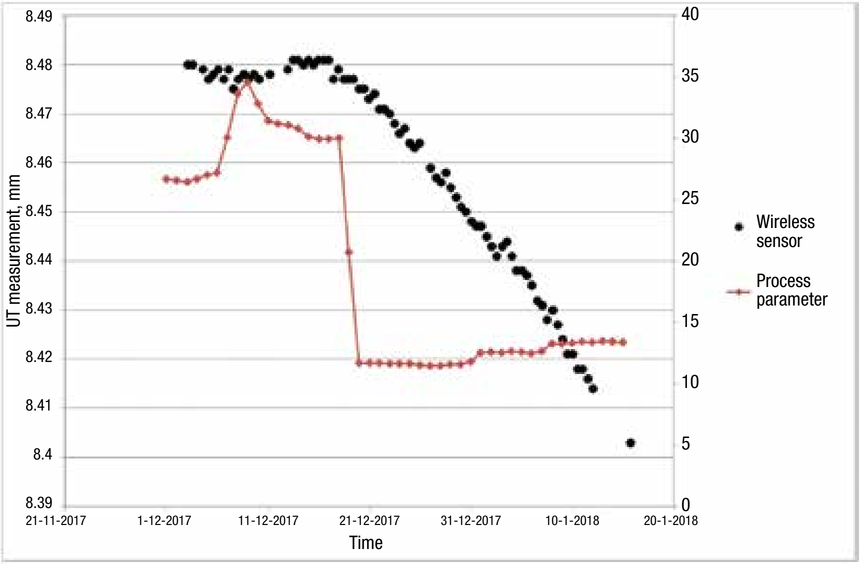


FIGURE 6. **Process monitoring revealed the connection between a specific process condition and highly aggressive metal loss, allowing for rapid corrective action**

may run as many as 50 different crude sources and grades throughout a year. But using data from wall-thickness monitors to identify potential cause-and-effect relationships between other process variables and periods of aggressive metal loss can help to maximize production capabilities and reduce losses. In some situations, the loss results from an especially corrosive crude, but there are also situations where process changes or upsets have unleashed an especially destructive period (Figure 6). These can be spotted by analyzing the continuous thickness data, and these findings are examined by determining what else was happening during that time. Did a process variable change? Was the wrong corrosion inhibitor used, or were no inhibitors used when they should have been? Are there any other factors to examine?

The analysis shown in Figure 6 was used for review with a chemical company providing corrosion inhibitors to a petroleum refinery, and in this case, it was found that the formulation in use the previous week did not work as well with the particular crude running that day at the facility. Using corrosion measurement data, it was possible to fine-tune the selection process to improve formulations, matching additives with conditions.

Real-world lessons learned

Continuous metal-thickness corrosion monitoring, whether deployed sparsely to understand the overall corrosion picture, or in higher densities to understand the exact corrosion nuances of a specific area of the plant, supports the corrosion-mitigation strategies mentioned earlier. Data from the wireless sensors analyzed over time can determine the parameters of safe integrity operating windows and indicate the effectiveness of corrosion inhibitors. All of these elements work together to measure and mitigate this complex problem, regardless of the crude feedstock characteristics. Ultimately, knowing the current integrity of the plant, and how it is coping with the ever-changing corrosion burden, means that the facility can be driven to its maximum operating capability. ■

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Unified Operational Environment Improves Process Safety

A unified gateway station and related components increase availability to improve operations and safety

Wataru Nakagawa and Eugene Spiropoulos
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IN BRIEF

In information technology (IT) security circles, the most important acronym is CIA: confidentiality, integrity, availability. In industrial control security, the corresponding acronym is AIC: availability, integrity, confidentiality. Availability and uptime are critical for process plants and facilities, and are also a key determinant of safety because plants that have poor availability are unsafe. High-availability plants minimize the unplanned shutdowns that can cause serious safety incidents, so both cybersecurity and process safety are dedicated to maximizing availability.

In process plants, and in upstream oil-and-gas applications, such as offshore platforms or subsea wells, there is often a hybrid control system, consisting of a distributed control system (DCS), multiple programmable logic controllers (PLCs) and a supervisory control and data acquisition (SCADA) system with remote controllers.

Because of this, there has been a need for a unified operation and monitoring environment to ensure safety, security and high availability. Unifying these control systems is not always as easy as it may appear, with many plants and platforms having more than one type of control system — such as a DCS and several PLCs. Sometimes a wide variety of controllers from different vendors are used, and, depending on their own specific applications, they are operated and monitored via their own operating stations and software.

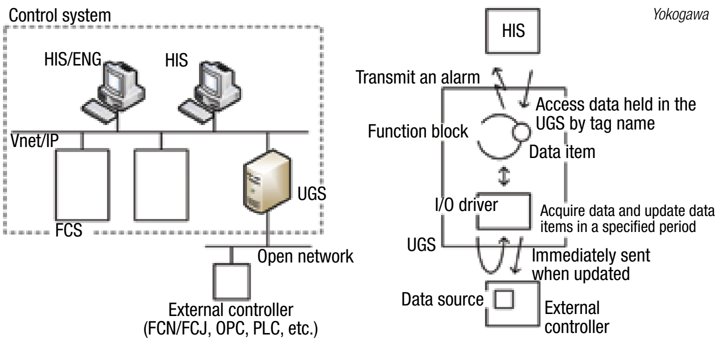

FIGURE 1. This diagram shows the typical position of a unified gateway station (UGS) in a control system along with its internal configuration

When control systems, operation and monitoring systems (including alarm monitoring and safety control systems) are disparate and use different screens, programming systems and functions, the result is an often an inefficient set of systems that decrease the safety of the entire installation.

There has been a need to establish a unified operation and monitoring environment that permits the operator to operate and monitor the controllers on the same screen, despite the differences between types and brands of controllers.

Unified operations, critical redundancy

In response to this need, the concept of a unified gateway station (UGS) has been created for process plants and facilities needing to integrate many subsystems into a unified system. This concept is supported by multiple vendors, with each configuring their systems in a different manner, but in all cases, the required functionality and desired operation is similar.

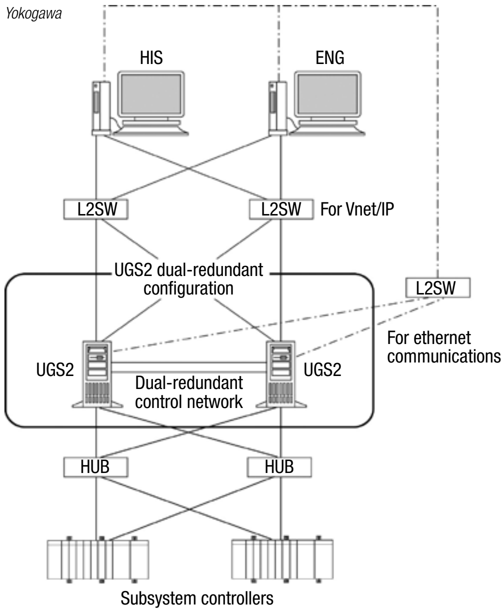

FIGURE 2. A dual-redundant network configuration provides the high availability and reliable connectivity required for a unified gateway station (UGS)

A UGS is installed between the DCS and all the external controllers. It performs continuous bi-directional communications frame conversion for process data and alarms to the DCS regardless of type or vendor of controller (Figure 1). Using a UGS provides additional SCADA expandability to the DCS without reducing the functionality of the DCS itself.

Because the UGS provides the main interface to all of the control systems, its uptime is critical. This can be provided by using two redundant PCs, which can handle a variety of interfaces and a large number of subsystems. This improves upon the availability of the system because many of the controller subsystems depend on the operation of a single general-purpose PC. A high-availability configuration also prevents data loss and downtime by contributing to long-term stable operation.

Therefore, a UGS should be designed to be a high-availability connectivity solution (Figure 2). A typical dual-redundant package will consist of two PCs configured as a logical unit to achieve a gateway function for the subsystems. These two units share an identical Vnet/IP address (domain and station numbers), providing other stations with transparent access to the UGS tag data without considering which one of the redundant PCs is active, and which one is on standby. For redundancy, both units are connected using a dual-redundant control network. Only the active station downloads the engineering data, but it synchronizes the standby unit using the dual-redundant control network (Figure 3).

If failure of the operating side PC occurs, it automatically fails over to the standby PC. Importantly, this switchover takes less than a second, which means the connected Vnet/IP stations and subsystem controllers are not affected. This is so, even when the system is performing sequential control of multiple tasks, as in a batching system. This minimizes the probability of data loss and ensures there is no interruption in control. Thus, high availability has been preserved, and safety-critical functions have not been affected.

As important as high availability is to maintaining plant safety, having a unified operating environment is just as important. As many after-incident reports have shown, operators moving from one operator interface to another tend to make mistakes, which can have serious consequences.

With the UGS concept, the same station, for example the DCS operator interface, can be used to communicate with and monitor all the controllers and subsystems in the control network, regardless of vendor. The UGS provides an I/O driver that solves the differences among protocols of the external controllers by supporting internal DCS communications protocols, IEC61850, OPC-DA, Ethernet/IP, Modbus RTU, Modbus TCP IP and other interfaces. When redundant communication is

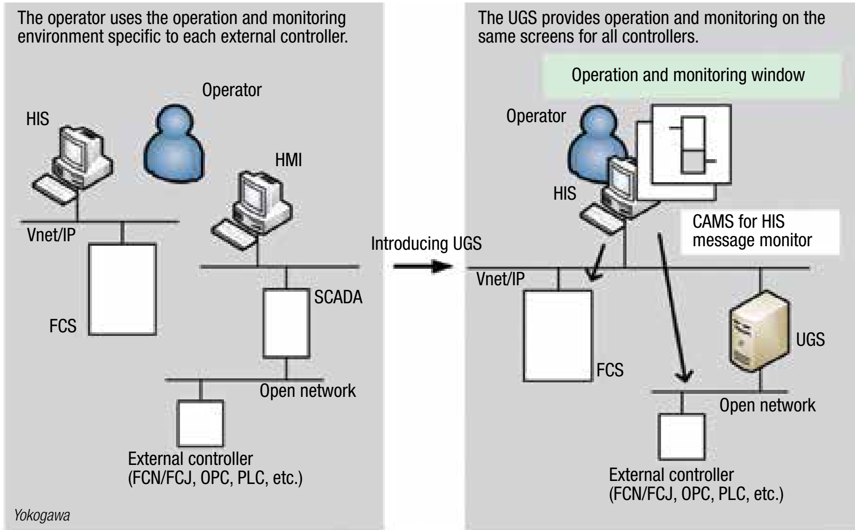

FIGURE 3. On the left diagram, different operator interfaces are used to monitor different systems. On the right, a unified gateway station (UGS) provides monitoring on the same screens for all the controllers in a plant or facility (HMI = human-machine interface; HIS = human interface station; FCS = field control station)

needed to any controller, it can also be supported, either directly, or by a third-party library from an OPC vendor. The UGS continually monitors the status of communications with external controllers, alerting operators to any issues.

The UGS controls and monitors subsystem communication data by treating it the same as the DCS faceplate blocks. It also allows graphics and trends to be handled as native DCS tags on the operator station (Figure 4).

Unified alarm monitoring

The UGS translates the function blocks in each controller into native DCS function blocks, and vice versa.

In a DCS, function blocks are often used for alarm monitoring, in the same way as for data operation and monitoring. Monitoring external controllers is done by monitoring alarms generated in the function blocks.

The function blocks of the UGS convert alarms generated in external controllers, and can also detect and generate alarms. The data item faceplate, and the annunciator faceplate, enable alarm monitoring of external controllers that do not have alarm functions. For all alarms, the same standard settings are used, providing consistency among systems. Having a unified alarm-monitoring system for all controllers and all function blocks produces a significant increase in process safety.

Operating at scale

To handle the large data volumes in an entire plant or facility, the UGS should be capable of accommodating a large number of tags, typically up to 100,000 with 450,000 data items, and should be able to connect to hundreds of external controllers. At that size, a UGS can acquire 6,400 data items per second from external controllers and send 640 data items per second to them, and the operator stations can read 6,400 data items per second from and write 640 data items per second to the UGS itself.

A unified set of engineering functions should be part of the UGS, including import functions. With this capability, engineering information defined for the UGS can be maintained as part of a project, the same as for all the other DCS engineering information. A smart import function of the DCS, an OPC Browse command, a CSV import command for general data files in the comma separated values format, and other options should be available to import data. After importing data, tags should be automatically generated. The next step should be the downloading of configuration information to the operator station and the UGS. This two-step process allows the operator station to access the external controllers.

Especially important for oil-and-gas applications is the capability to apply online partial changes. This is also true for sequential operations in process plants. The UGS should

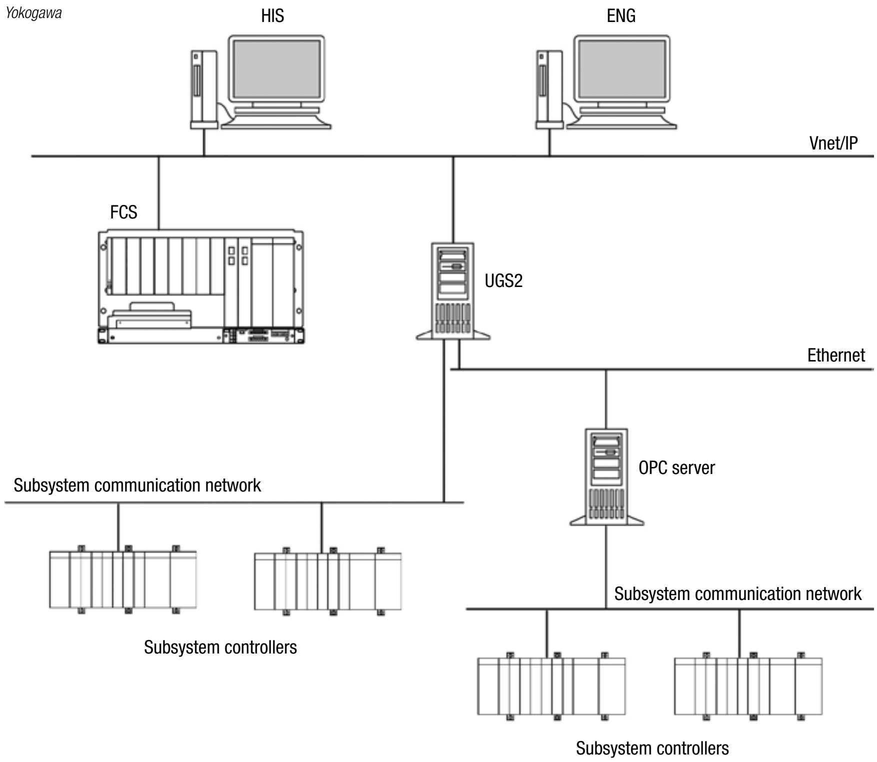

FIGURE 4. The unified gateway station (UGS) in this system architecture diagram acts as a gateway between the DCS and the subsystem controllers

therefore be designed to allow online modifications to the screen graphics. Online addition, modification and deletion of external controllers and tags should also be supported. Finally, online switching among import modes, such as smart import, OPC browse command and CSV import, should be supported.

When the configuration of an external controller is modified, or devices connected to the controller are replaced, the connection between the UGS and the controller should be able to be switched on or off by the controller monitor block of the UGS. This prevents a modification or replacement from accidentally affecting the DCS.

Concluding remarks

A UGS increases and improves upon the functionality of a standard DCS system by integrating stand-alone PLCs and SCADA systems into a unified operational interface, which is particularly important for installations with many subsystems. The UGS should provide a simple unified configuration to handle a variety of interfaces and a large number of subsystems using one set of redundant PCs with auto-switchover to preserve operation and data flow. The UGS should be capable of handling large numbers of subsystems and high data volumes, and various protocols — such as Modbus, Ethernet/IP, OPC and IEC 61850 — should be supported for communication with subsystems.

The UGS controls and monitors subsystem communication data by treating each subsystem as a native DCS controller faceplate block, as well as by allowing each subsystem's graphics and trends to be handled as native DCS tags on the operator station. The DCS operator station can thus perform operational control and alarm monitoring of subsystems exactly as if they were DCS native systems.

A UGS improves process safety by providing a unified operating interface, unified alarm management capability and a high-reliability redundant system to create a robust, high availability platform to improve process safety. ■

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Feature Report

Part 2

The Value of Safety Instrumented Systems

A safety instrumented system (SIS) is important to ensure the safe operation of a plant. The SIS requires up-to-date sensors — recent developments in vortex flowmeters are presented here

Mike Klein
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There are four key areas of concern for chemical producers that are always top of mind in daily operations. These are, in no specific order, ensuring safety, optimizing production efficiencies, minimizing emissions and improving reliability. In many ways, these concerns are interconnected and are governed by many of the same standards.

To meet the stringent standards that govern this industry, safety instrumented systems (SIS) are one of the solutions that make the difference, precisely because they not only impact worker safety, but also environmental and safety issues around the plant. Not only do these risks impact workers and the environment, they also impact the financial health of a company. Any time something happens that violates codes, standards and regulations, it can have a significant impact on the balance sheet.

Though engineers can create systems that monitor and manage the safety and operations of a plant down to the smallest detail, it doesn't always mean that is what's called for. If a shutdown is triggered over a deviation from standard that would ordinarily be within acceptable tolerances, it can mean extra costs, a recalibration or repair of critical equipment that might have been impacted by the shutdown.

A safety system is separate from a control system and is focused on the prevention of accidents with the understanding that it will shut down the plant should an accident occur. A safety system is the final layer of protection a plant has to ensure the safety of its people and the environment.

Of the many standards that govern the design and implementation of safety systems, the most notable and commonly applied one is IEC 61511, established by the International Electrotechnical Commission (Geneva, Switzerland; www.iec.ch), which applies to the chemical process industries (CPI), including the chemical, petroleum refining, petrochemical, pharmaceutical, pulp and paper, and power sectors.

FIGURE 1. The quad vortex sensor has four independent transmitters and sensors, a configuration that is recommended for SIL 3 applications

Sensors are the key enabler

The primary enabling component of a quality safety system is the field instrument, or sensor. Top-quality sensors are key to helping engineers design and maintain the established protocols that help a chemical plant meet regulatory requirements. These sensors are typically the first devices to be exposed to the unsafe condition that will ultimately trip the safety shutdown process. The challenge is to have sensors that work together to accurately assess the process to detect an unsafe condition, but that do not report a false reading that might lead to an unnecessary shutdown.

Aspects of the design process engineers need to consider when developing an effective loop design are, that it must meet the risk-reduction requirement levels and establish the correct probability of failure. Once those variables and parameters are known, an engineer can calculate the safety integrity level (SIL) requirements.

The results from those calculations, and using the standards set in IEC 61511, will determine sensor choices. In addition, a history of use and failure rate of previously used sensors within the user's own facility will be a factor in selection.

These are only a few ways a chemical producer can determine the type of sensors they invest in. What is clear, however, is that chemical producers will look very carefully at all options when selecting sensors for a comprehensive SIS system to ensure the best possible system based on the SIL requirements and the effective operations of the plant.

The vortex meter option

In the past, vortex meters have gained the reputation as being unreliable and a poor choice for chemical applications. This was mainly due to early technology and application challenges, which included low-flow cutoffs that didn't measure down to zero flowrate, extreme vibration applications that might not have been suitable due to the potential for inaccurate flowrate measurements, and some designs that were prone to plugging.

In recent years, many suppliers of

VORTEX METERS

Vortex flowmeters work on the vortex shedding principle as it was observed and noted by Theodore von Kármán, a Hungarian-American physicist. He first described the effect he observed when a non-streamlined piece of material — often called a bluff body — is placed in a fast-flowing stream. The liquid, or steam, will separate from the object on its two downstream sides; when detached, it will curl back on itself, forming vortices, also called eddies or whirlpools. You can see this principle in action if you put a rock in a fast-moving stream, for example.

On the side of the bluff body where the vortex is formed, the fluid velocity will be higher and the pressure lower. As the vortex moves downstream, it gets stronger and bigger, eventually detaching or shedding itself. A vortex is then formed on the other side of the bluff body. The alternating vortices are spaced at equal distances. The frequency of vortices shedding is what is measured.

A vortex meter has no moving parts, which makes it highly suitable for corrosive materials. The meter has external sensors that sense the vortex shedding indirectly through the force exerted on the shedder bar — the bluff body — that is inside the meter.

Vortex meter sensors are modular, inexpensive and easy to replace. They can operate under a wide range of temperatures — from cryogenic liquids to superheated steam.

New developments

New configuration designs are making implementation of SIL-rated vortex sensors easier and safer for use in extreme or aggressive applications governed by stringent safety requirements.

Today, there is the dual vortex option and the newer quad vortex option (Figure 1). Both have strong capabilities and fit a variety of systems and applications.

The dual vortex is a safe and simple drop-in solution for SIL 3 applications. The dual has two independent transmitters and flow sensors, providing a 1:1 or 1:2 voting configurations, which determines the number of error readings before the system triggers a shutdown.

The quad vortex has four independent transmitters and sensors with two separate shedder bars acting as bluff bodies to create the vortices needed to accurately measure the flow. This configuration is recommended for SIL 3 applications where 2:3 voting is needed.

The benefits of a quad vortex over a dual vortex are that a quad gives the ability to put many sensors and transmitters in a single spool piece that makes installations easier. Less space is required for flow conditioning within the pipe, giving the chemical producer more flexibility in how and where to apply it within the safety system.

The 2:3 voting offers a significant benefit in that it prevents a single reading that is off from tripping the system into a shutdown. With the 2:3 voting, it will take at least two skewed readings to trigger a system shutdown, thereby preventing false trips, which can become costly.

In each instance though, it's important for engineers to determine which option will best meet the requirements they must work within when designing the plant safety system. ❑

vortex flowmeters have overcome these issues, thereby boosting the capabilities of the meters and making SIS-rated vortex sensors a good fit in most chemical applications (see sidebar on this page). However, it is important to make sure the device selected has a third-party certification of its SIL capability. The exida company (Sellersville, Pa.; www.exida.com), for example, is an industry leader in providing SIL certification for devices.

Manufacturers of vortex meters strive to ensure their meters and sensors meet the SIL certification and are tagged as such, including shipping devices with a certificate stating the usability in SIL applications. These are important considerations to a chemical processor when designing a robust SIS system.

An application example

A chemical producer in the northern part of the U.S. had an application in a unit that utilized a feed stripper to remove dissolved oxygen from storage feed tanks, which is an important step in the process that ensures fewer process upsets. The producer had installed a safety instrumented system for the protection of their plant personnel, aiming to eliminate the risk of two-phase flow from high-pressure hydrotreating reactors through the feed drum back to the feed stripper.

When first engineering this safety instrumented system, two out of three voting (2:3) was selected to reduce the chance of a spurious trip and to simplify online critical alarm testing. The differential pressure flowmeter solution they initially opted for consisted of multiple pairs of impulse lines off a single orifice plate. Those impulse lines had a number of challenges; chief among them was that they were very difficult to zero at no flow. In addition, they were also prone to plugging and, especially in the winter months, freezing. The lines had to be heat traced due to the cold winters, and added to that, there were a large number of potential leak points. Challenges like these bring added headaches and increased complexity to installations, along with unexpected failures and the potential for false trips.

The SIS quad vortex solution provided this user with a more efficient solution. Some of the benefits they realized after implementing the quad vortex included the following:

- The elimination of impulse lines and complex heat tracing, thereby reducing capital expenditures and install time of associated additions
- No potential for plugging or leaking due to the all-cast, all-welded design that cuts down on operating expenditures
- Online removable sensors to keep the process up and running, thereby maximizing availability
- The simple bolt-in installation reduces installation time and reduces potential leak points to only two

Putting it all together

With vortex meters now a proven technology for chemical producers capable of measuring the flow of extreme materials over a very wide range of temperatures, they can now be seriously considered when creating a safety instrumented system.

Regulations governing the environment and worker safety have grown more stringent over the past few decades. Having the right tools and instruments to meet — and even exceed — those regulations has benefits beyond the obvious of meeting those regulations. It means more efficient and reliable operations, greater worker safety, fewer shutdowns and less unexpected expenses connected with unplanned shutdowns.

Having a strong and well-designed safety system in place just makes good sense. ■

Edited by Gerald Ondrey

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Design and Calculation Methods for Uniflow Cyclones

Uniflow cyclones can be effective solid-gas separation equipment when space is limited. Presented here are design and calculation methods for uniflow cyclones aimed at widening the industrial usefulness of these devices

Ulrich Muschelknautz
MK Engineering

Cyclone separators are, in addition to fabric filters, electrostatic precipitators and scrubbers, the most commonly applied separators for removing solid particles from gases. They are used either to keep the exhaust air of a plant clean or to obtain powdery product from process gases. Compared to the other types of separators mentioned, cyclone separators have several major advantages. Their relatively simple and robust construction and operation result in comparatively low investment and operating costs in many cases. Also, they can be used in processes requiring high temperatures (up to 1,200°C), high pressures (over 100 bars) and high solids loads (for example, 30 kg solids per kg gas). Finally, they allow the reuse of the separated particles.

A competitive alternative to the standard cyclone for gas-solids separation is the uniflow cyclone. Like a pipe, a uniflow cyclone has gas and particles passing through it in only one direction. Clean gas and separated particles leave the device at the same end. The vortex flow is generated either by swirl vane inserts or by a tangential inlet at the entrance. Compared to standard cyclones, uniflow cyclones are much more compact, which makes them particularly interesting for applications with limited space. They also allow a simple and cost-effective implementation in piping systems.

Although the principle of uniflow cyclones has been known for a long time, few studies on design and calculation methods for this type of cyclone have been published. These investigations have been limited to specific applications of uniflow cyclones, such as a short-contact-time reactor for high-solids-loading gases [1]. This article provides information on fast design and calculation methods for the performance of uniflow cyclones, inlcuding separation efficiency and pressure drop. The performance data are aimed at widening the industrial use for uniflow cyclones, an accurate, reliable and inexpensive separation method.

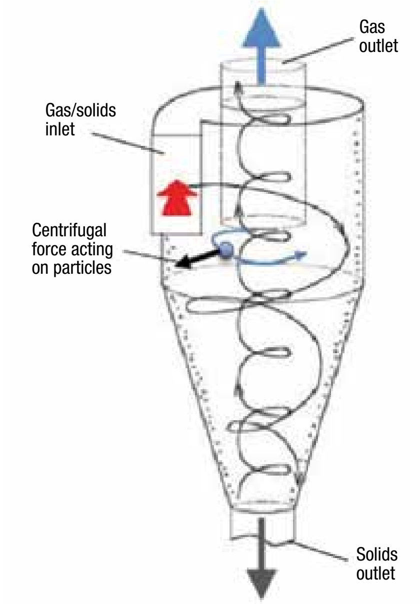

FIGURE 1. Standard cyclone separators use centrifugal force to remove solids from swirling gases

Design criteria for cyclones

In recent years, comprehensive experimental and theoretical studies of uniflow cyclones have strongly improved understanding of this equipment type and has led to approved design criteria and calculation methods, similar to those already available for standard cyclones. Applying those proven calculation models for both cyclone types, which are both based on the same physical concepts, indicates agreement with experiments on the following points:

- Uniflow cyclones can be more efficient than standard cyclones if the space is limited to close to the volume needed for the uniflow cyclone to achieve optimum performance, and the available pressure drop is low. In other words, uniflow cyclones can achieve a higher separation efficiency per volume if

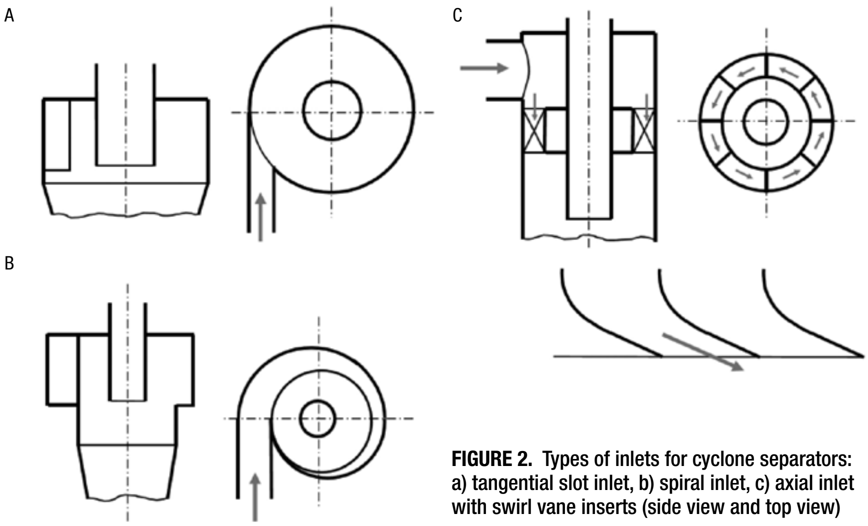

FIGURE 2. Types of inlets for cyclone separators: a) tangential slot inlet, b) spiral inlet, c) axial inlet with swirl vane inserts (side view and top view)

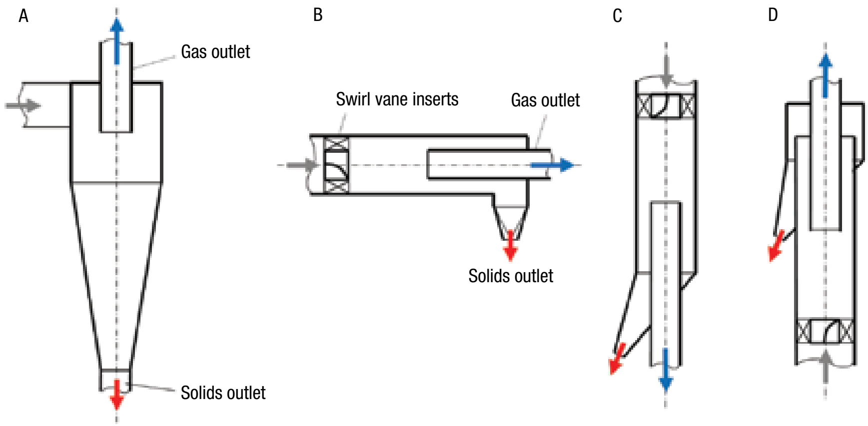

FIGURE 3. Diagram (a) shows a standard cyclone with tangential inlet, and diagrams (b), (c) and (d) show uniflow cyclones with axial inlets. A horizontal orientation is shown in (b), vertical downward in (c) and vertical upward orientation in (d)

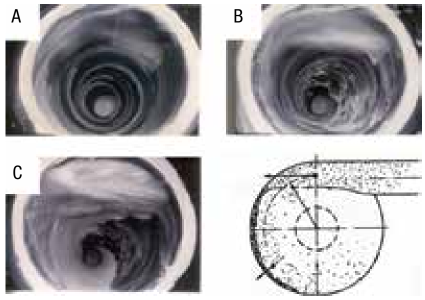

FIGURE 4. Images of dust strands and dust mats in a cyclone with a diameter of D_c = 800 mm, vortex finder diameter DVF = 285 mm with different loadings of washing powder (d_{50} = 500 µm): a) μ_e = 0,1, b) μ_e = 1 , c) μ_e = 10 (see Ref. 9)

the available pressure drop is low.

- If volume and pressure drop are not restricted, standard cyclones are more efficient than uniflow cyclones, but require significantly more volume. The efficiencies of both cyclone types approach each other with decreasing gas volume flow and with increasing pressure drop, particle size and particle density of the feed.

Cyclone operation

Cyclone separators have been in industrial use for over 100 years and still are the subject of intensive research and development (see Ref. 2 and 3, for example). A detailed description of physical fundamentals, designs, planning and commissioning, operation and maintenance of cyclone separators is given in Ref. 4.

The two essential performance parameters of a cyclone are its separation efficiency and its pressure drop. The latter determines its energy consumption. Goals of the cyclone design are generally to achieve the maximum possible separation efficiency with the lowest possible pressure drop for a given task. In addition, cyclone operation seeks to minimize erosion of cyclone walls by abrasive particles and prevent deposits on the cyclone walls in the case of adhesive particles, especially in areas of the cyclone with low flow velocity or flow detachment. And all of these design parameters ideally should be achieved with a limited construction volume.

In a cyclone separator, the gas to be purified from particles is set into a vortex flow with high vorticity (Figure 1). Due to the density difference between the particles and the gas, the particles sediment, under the action of centrifugal force, outward in the radial direction against the cyclone wall, where they move with the downwards rotating gas flow (only at high loads due to gravity) and are transported to the solids outlet. The cleaned gas exits the separation chamber, after reversal of direction, concentrically to the cyclone axis located at the gas outlet tube, also called the vortex finder.

The swirl is generated by introducing the particle-laden gas stream into the cyclone with a tangential component. This is realized either by a tangential slot, a spiral inlet or by an axial inlet with swirl vanes inclined to the vertical axis of the cyclone (Figure 2).

Calculation models

For the computation of the performance data of standard cyclones, there are proven analytical models with high accuracy, which in practice, are often advantageous over numerical simulations with long computation times. One of those models is based on an equlibrium orbit concept according to Ref. 5 and is described in Ref. 2–3 and 5–13. This model has been applied successfully in a broad range of industrial applications (see

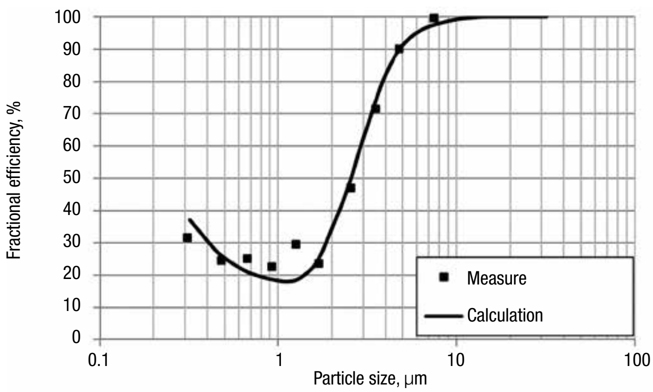

FIGURE 5. The graph shows measured [*11*] and calculated (according to Ref. 12) fractional efficiency curves of a standard cyclone for natural gas purification from solid particles. Cyclone diameter is 220 mm (8.7 in.), cyclone length (pure cylindrical shape) is 1,200 mm (47.2 in.), gas volume flow is 300 m^3/h, solids loading (lb solids / lb gas) is 0.00056, and separation efficiency is 94.3%

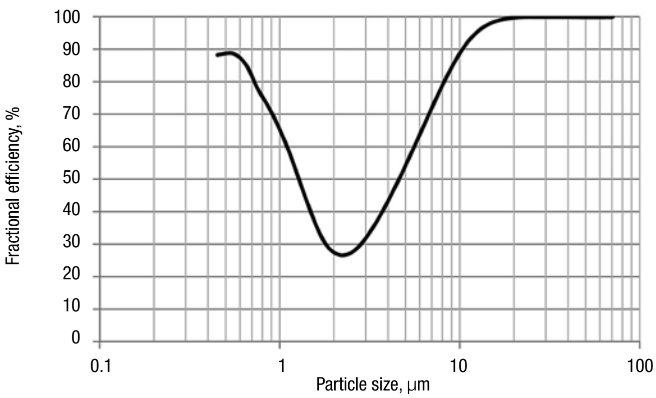

FIGURE 6. This graph shows the measured fractional efficiency of a uniflow cyclone for collecting limestone particles (mass mean diameter d_{50} = 20 µm and d_{10} = 3 µm). The cyclone diameter is 192 mm (7.6 in.), the cyclone length (pure cylindrical shape) is 1,500 mm (59.1 in.), the gas volume flow is 1,000 m^3/h, solids loading: 0.0016 lb solids / lb gas, separation efficiency is 87.5%, pressure drop: 3,250 Pa (0.47 psi) (see Ref. *20*)

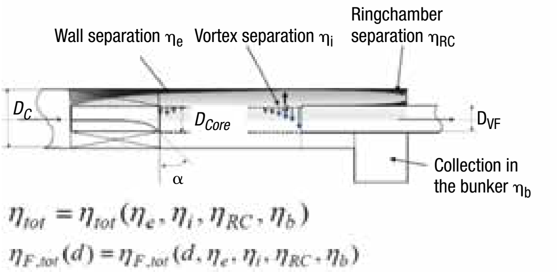

FIGURE 7. In a uniflow cyclone, the separation process has several components, as shown here

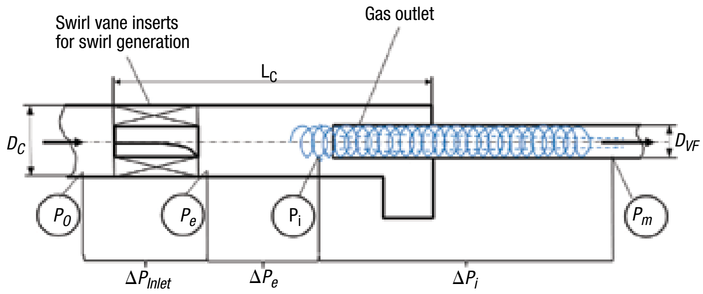

FIGURE 8. This diagram shows the pressure drop in a uniflow cyclone

for example, Ref. 14 and 15).

Similarly, industrial practice would benefit from a reliable analytical calculation model for uniflow cyclones. Previous analytical approaches to calculate the separation efficiency of uniflow cyclones are mostly based on the idea of a sedimentation process that takes place under the effect of centrifugal force. This concept insufficiently takes into account the drag force on the particles of the gas flowing inward toward the gas outlet. Since this drag force has a decisive influence on the cyclone separation efficiency, the models do not correctly reflect fundamental correlations, such as the dependence of the separation capacity on the vortex-finder diameter or the cyclone length. In addition, the re-entrainment of already separated particles from the cyclone wall into the clean gas and the influence of the solids loading on the performance data are not taken into account.

Against this background, a new analytical model was developed for the calculation of the separation efficiency and pressure drop of uniflow cyclones for practical design work. This model uses the same physical concepts as the equlibrium orbit model cited above. This approach makes sense because the principle of particle separation in both types of cyclones is the same: particle separation occurs through outward centrifugal forces generated by the swirl flow, reduced by the inward drag forces of the gas flowing to the gas outlet. The novel model has been validated with extensive experimental data [*16–22*].

TABLE 1. RRSB PARTICLE SIZE DISTRIBUTIONS OF THE CONSIDERED DUSTS				
Dust	d_{min}	d_{max}	$d_{50,3}$	n
Semicoarse dust	0.5	300	50.5	0.9
Fine dust	0.2	200	17.5	0.95

Calculation method for standard cyclones. In standard cyclones, the separation efficiency depends crucially on the solids loading of the flow at the cyclone inlet. Solids loading is defined as the ratio of dust mass flow to gas mass flow, as shown in Equation (1).

$$\mu_e = \dot{M}_s / \dot{M}_g \tag{1}$$

The swirling flow can — similar to the gas flow in pneumatic transport — carry only a very limited dust load, the so-called limited loading. If the inlet loading (μ_e) exceeds the limited loading (μ_{lim}), the surplus particles are deposited on the wall of the separation chamber immediately after entry of the flow into the cyclone.

Thus, in the cyclone inlet region, a first separation stage takes place (also called wall separation). All particles carried by the vortex flow then undergo the second separation stage: the separation in the inner vortex of the cyclone. Figure 4 shows the wall separation very impressively in a standard cyclone with a diameter of 800 mm. With increasing solids loading at the cyclone inlet, an increasing portion of the incoming solids is deposited immediately after entry to the cyclone wall.

Figure 5 illustrates the influence of the solids loading on the course of

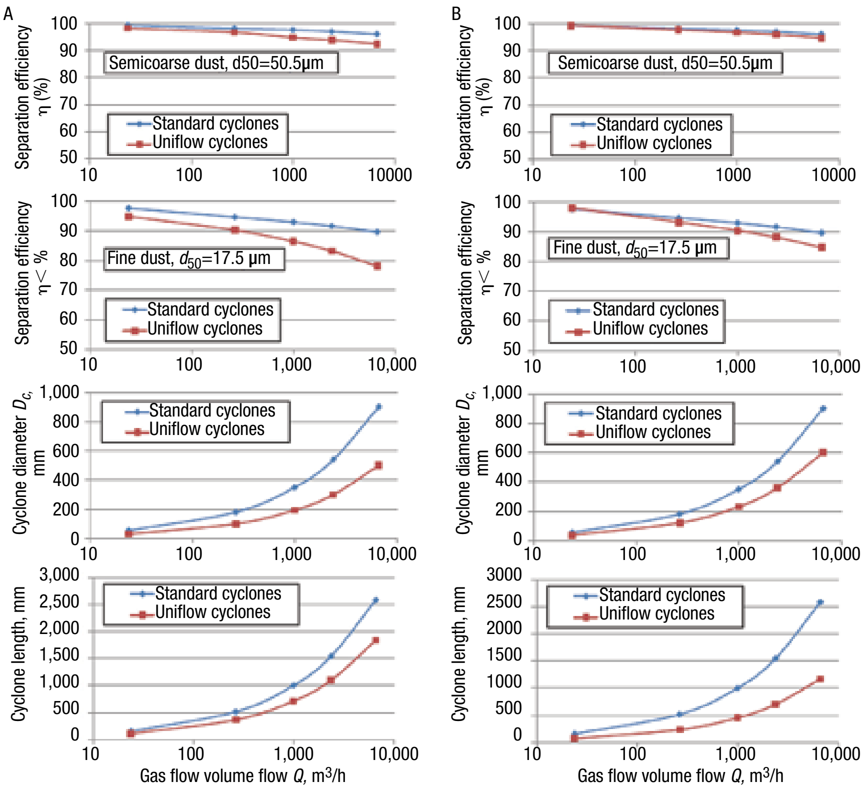

FIGURE 9. These graphs compare single standard cyclones and single uniflow cyclones (a) and four parallel uniflow cyclones (b) for purifying different gas volume flows (24 m³/h, 266 m³/h, 1,000 m³/h, 2,400 m³/h and 6,640 m³/h. All cyclones have the same pressure drop of about 4,000 Pa, and are geometrically similar, thus having the same inlet and outlet velocities. The main dimensions are shown in the two lower figures. Separation efficiencies are calculated for semicoarse dust with $d_{50,3}$ = 50.5 µm (at the top) and for fine dust with $d_{50,3}$ = 17.5 µm (at the middle) (For more details, see Ref. 25)

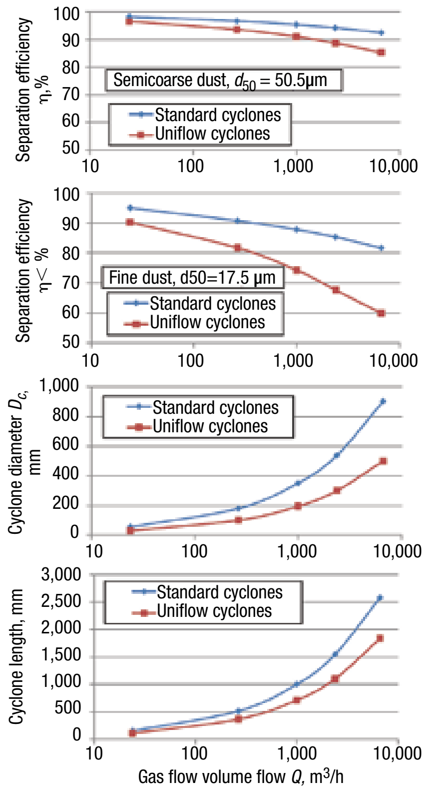

FIGURE 10. **Presented here is an exemplary comparison of single standard cyclones with single uniflow cyclones for purifying different gas volume flows (24 m^3/h, 266 m^3/h, 1,000 m^3/h, 2,400 m^3/h and 6,640 m^3/h). All cyclones have the same pressure drop of about 1,000 Pa and are geometrically similar, thus having the same inlet and outlet velocities. The main dimensions are shown in the two lower figures. Separation efficiencies are calculated for semicoarse dust with $d_{50,3}$ = 50.5 μm (top) and for fine dust with $d_{50,3}$ = 17.5 μm (middle) (For more details, see Ref. 25)**

the fractional efficiency curve, measured and calculated for a standard cyclone. For the case shown in Figure 5, the curve no longer drops to zero, but passes a minimum and increases as the particle size decreases. That is, finer particles are increasingly precipitated. This can be explained by a burying of fine particles below the solids strand on the wall deposited immediately after entry. The burying of fine particles increases with increasing solids loading at the entrance. For no burying to take place, this would be indicated by a steadily decreasing course of the fractional separation efficiency.

Similar behavior is also observed in uniflow cyclones (Figure 6). Immediately after entering the device, particles can form more or less pronounced strands at the cyclone wall, depending mainly on the curvature of the inlet vanes, the solids concentration and the mean particle size of the solids feed. In this case, the fractional efficiency curve passes a minimum similar to what has been observed in standard cyclones.

The model for standard cyclones, as described in the references, assumes a limited loading capacity of the gas stream splitting the separation process into two steps. At any solids loading, μ_e, in excess of this critical loading, μ_{lim}, the solids are immediately separated from the gas at the inlet to the cyclone. The solids remaining in the gas are separated in the cyclone barrel and in the inner vortex below the gas outlet tube with a second, inner separation efficiency, η_i. Total separation efficiency of the cyclone is described in Equation (2).

$$\eta = \left(1 - \mu_{\mathrm{lim}} / \mu_{\mathrm{e}}\right) + \left(\mu_{\mathrm{lim}} / \mu_{\mathrm{e}}\right)\eta_i \quad (2)$$

Uniflow cyclone calculation

Analogous to the model for standard cyclones, it is assumed that both separation processes also occur in uniflow cyclones (Figure 7). The first separation takes place inside the swirl vane inserts for swirl generation and subsequently in the separation chamber due to exceeding the limited load ratio, μ_{lim}, of the uniflow cyclone. If the load ratio at the inlet μ_e exceeds the limited load ratio, μ_{lim} , the excess mass fraction will be removed immediately after the gas jet enters the cyclone, and only a small fraction that is restricted by μ_{lim} will undergo the centrifugal separation process in the inner vortex of the cyclones.

In a deviation from standard cyclones, uniflow cyclones have a third separation process that has to be taken into account. In contrast to standard cyclones, the solids discharge in uniflow cyclones is located close to the gas exit. Furthermore, a considerable part of the gas flow passes through the ring chamber between the cyclone wall and the vortex finder pipe before exiting

through the gas outlet pipe. Due to these characteristics, particles carried into the ring chamber can be re-entrained back into the gas outlet. The re-entrainment rate depends on the cyclone geometry and on the operation data. The efficiency of the gas-particle separation within the ring chamber is denoted by η_{RC}.

Finally, the collection efficiency of the bunker has to be taken into account, as in standard cyclones. Thus, the total separation efficiency, as well as the fractional separation efficiency of the cyclone, are functions of those four single separation efficiencies (Figure 7).

The method for calculating the separation in the inner vortex has been described in detail elsewhere [*23, 24*]. For low loadings (μ close to 0.001), this separation mechanism is dominant and its efficiency is expected to be close to the total separation efficiency. With increasing solids loadings, the wall separation becomes more and more important and already below a solids loading of 0.01, the wall separation can become the dominant separation mechanism, depending mainly on the cyclone size, the tangential velocity at the inlet and on the size distribution and density of the particles.

Analogous to the calculation model for reverse-flow cyclones, the pressure drop of uniflow cyclones is calculated as the difference of the total pressures between a position in front of the cyclone inlet *o* and a position *m* far beyond the opening of the gas outlet where the swirl strength of the vortex flow in the gas outlet has decreased to approximately zero due to wall friction (Figure 8). As in standard reverse-flow cyclones, the total pressure drop is divided into three parts: the pressure drop in the inlet, Δp_{inlet}; the pressure drop in the separation chamber, Δp_e, between the mean entrance radius and the position *i* at the vortex finder radius r_{VF}; and the pressure drop, Δp_i, in the gas outlet tube, including the inlet pressure drop at the tube inlet between the position *i* and the measurement position *m*. At low loadings (below about 0.01), the third pressure-loss component, Δp_i, accounts for the major part of the total pressure drop. The exact value depends on the geometry and operating data of the cyclone. At high loads (greater than 1), Δp_i is still roughly 50% of the total pressure drop.

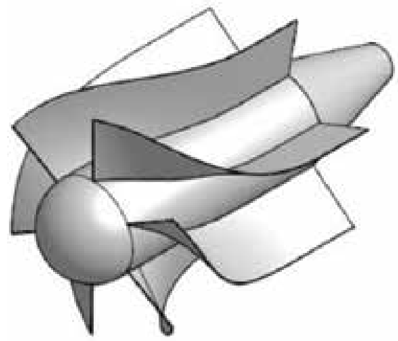

FIGURE 11. This is a 3-D drawing of swirl-vane inserts for pressure drop reduction in a cyclone

The pressure drop calculation method is based on the same gas velocity field that is used to calculate the separation efficiency. Therefore, both calculation quantities are closely

FIGURE 12. **The photos show swirl-vane inserts installed in standard cyclones for pressure recovery. The left image is a vortex finder with swirl-vane inserts (dia. = 2,300 mm (90.6 in.) in a recirculating cyclone at a power plant, operated at 900°C [*15*]. The right image is of manufactured swirl-vane inserts (dia. = 650 mm (25.6 in.) to be installed in decoking gas cyclones applied in a steamcracker, operated at 450°C (842°F)**

linked within this calculation model. In addition, the model allows the calculation of the pressure loss of a uniflow cyclone for any positions of the measuring point for the pressure in the gas outlet line, for example, at positions only a few inner diameters behind the gas outlet tube opening (that is, at a point where the gas flow still has a high vorticity). This is particularly useful for comparing calculation results with experimental data, as it is often measured within short distances to the gas outlet tube opening. For details of the pressure drop calculation, see Ref 24.

Comparing cyclone types

The calculation models for standard cyclones and for uniflow cyclones described above allow comparisons between cyclone types in a systematic way. With respect to industrial applicability, a key question is what amount of particles both cyclone types can remove from specified gas-solids flows. To address this question, properly designed uniflow cyclones and standard cyclones for purifying four different gas volume flows between 24 and 6,640 m^3/h (air at 20°C, 1.013 bars) carrying 2 g/m^3 dust are compared. All uniflow cyclones are geometrically similar and operate at the same static pressure drop of 4,000 Pa. The same applies to the four standard cyclones. In this example comparison, all considered cyclones are installed in a piping system with the same inlet and outlet gas velocity. The pressure drop is determined as the difference in static pressures between the inlet duct and the outlet duct. All cyclone configurations have been calculated for two dusts with different particle-size distributions (Table 1) and a particle density of 2,700 kg/m^3.

Uniflow cyclones for solving this problem have diameters between 30 mm (24 m^3/h) and 500 mm (6,640 m^3/h), whereas standard cyclones need diameters between 54 mm (24 m^3/h) and 900 mm (6,640 m^3/h), (Figure 9). The total lengths (including the length of the swirl generator) vary between 110 mm and 1,830 mm for uniflow cyclones, and between 150 mm and 2,580 mm for standard cyclones.

Thus, in the present case, uniflow cyclones are about 40% smaller in diameter and about 30% shorter than standard cyclones for purifying the same gas-solid flows at a given pressure drop, under typical conditions.

Note that an increase in the length of a uniflow cyclone beyond a value of L_C/D_C ~ 3 (Figure 8) does not improve its separation efficiency [*22*]. This constitutes an essential difference compared to standard cyclones, where the separation efficiency increases with increasing separator height, since the cut-off size decreases with increasing height below the vortex finder (as long as this height does not exceed a critical value where the inner vortex starts to

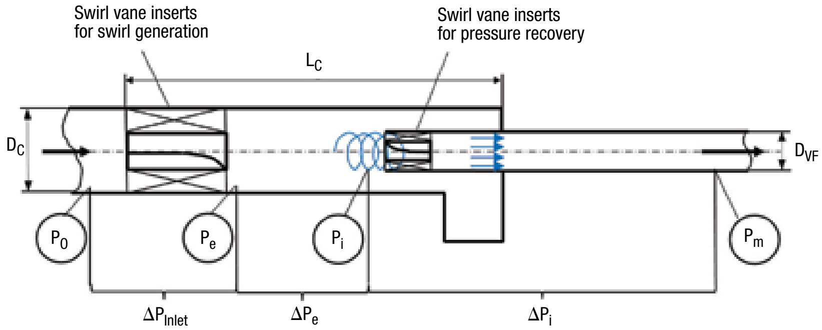

FIGURE 13. The uniflow cyclone shown here has swirl-vane inserts in the gas outlet for pressure recovery

bend to the cyclone wall and to suck off particles into the gas exit).

Figure 9 shows the separation efficiencies calculated for those cyclones for semicoarse dust with a mean particle size of 50.5 µm (at the top) and for fine dust with a mean particle size of 15.5 µm (at the middle). The particle-size distributions of both dusts are given in Table 1.

The results indicate that for a specified particle feed, the difference between the standard cyclone and uniflow cyclone separation efficiencies decreases with decreasing gas volume flow and correspondingly with decreasing cyclone size. Furthermore, the difference between the separation efficiencies of both cyclone types becomes smaller with increasing particles size. Both effects can be traced back to the fact that the cut-off size of a uniflow cyclone in its present design, according to Figure 3, is slightly larger than that of a comparable standard cyclone.

A corresponding conclusion can be drawn regarding the particle density, which follows from the model approach described above. For higher particle densities than the one specified above, the gap between both separation efficiency curves (standard cyclone and uniflow cyclone) shown in Figure 9 will decrease, and vice versa.

In order to achieve a separation efficiency close to that of a standard cyclone, and also for larger gas volume flows, a multicyclone arrangement consisting of several parallel cyclones is preferable [*25*]. Figure 9b shows the separation efficiency of an arrangement of four parallel uniflow cyclones, each having half the diameter of the uniflow cyclones considered in Figure 9a. In addition, some space has been left between the cyclone cells. The comparison of Figures 9a and 9b indicates that by this measure, the separation efficiency of the uniflow cyclone is lifted up and comes very close to the values obtained by the standard cyclone in the case of separating semicoarse dust. Furthermore, the volume of the uniflow cyclone is still much more compact than that of the standard cyclone and the cyclone length has even been reduced (due to the smaller cyclone cells).

Besides the separation efficiency, the pressure drop is the other key parameter characterizing the performance of a cyclone. It can be reduced by geometrical modifications that slow down the gas velocities at the gas inlet or at the gas outlet, or both, usually at the expense of its separation efficiency.

To give an example, Figure 10 shows the separation efficiencies of standard cyclones and uniflow cyclones for the above considered gas flows between 24 and 6,640 m^3/h with diameters and lengths as used in the above study (Figure 9), but with reduced circumferential velocities, which strongly reduce the pressure drop to 1,000 Pa. By comparing with Figure 9, it can be seen that the pressure drop reduction distinctly affects the separation efficiencies for fine particles, whereas semicoarse particles can be removed with almost the same efficiency as that of the cyclones with high pressure drop. This applies to standard cyclones as well as to uniflow cyclones.

A well proven method in industry to reduce the pressure drop of standard cyclones without affecting the separation efficiency is to install swirl vane inserts into the vortex finder, as shown in Figures 11 and 12. This device transforms rotational energy into pressure [*11*]. Without that measure, the rotational energy will be lost due to dissipation in the gas outlet pipe. Up to 60% of the total cyclone

pressure drop can be regained by swirl vane inserts, depending on the cyclone geometry and on the operation data. Similar results can be obtained by applying swirl vane inserts in the vortex finder of uniflow cyclones. For example, in a uniflow cyclone with a diameter of 300 mm (11.8 in.), a pressure-drop reduction by 43% could be achieved at a gas volume flow of 1,000 m^3/h, and by 40% at 2,500 m^3/h [*18*].

Cyclones in limited space

Often, space avaliable for dedusting a gas flow within an industrial plant is limited. If saving space is a high priority, or if there is a limited space available for purifying a given gas volume flow, the question arises whether under the space restrictions, a uniflow cyclone system may be preferable over its standard cyclone counterpart. This question is addressed by applying the above-mentioned calculation programs for standard cyclones and for uniflow cyclones.

To provide a fair comparison between both cyclone types, the most compact representative of a standard cyclone is considered. This is a cyclone with an axial inlet (Figure 2c), also called a swirl tube (Figure 14a). This cyclone type is preferably applied as a multicyclone series (that is, a system of many parallel cyclone cells within a common housing, and having a common solids hopper for solids discharge). Multicyclones are generally used to increase the separation efficiency beyond the level achievable by a single cyclone. Note that the minimum particle size that can be collected by a cyclone generally decreases with decreasing cyclone size. Principally, increasing the number of parallel cyclone cells and decreasing their size at the same time improves the efficiency of a multicyclone without changing the base area and without affecting its pressure drop, provided a uniform distribution of the gas and the solids feed into each single cyclone cell can be achieved, and bypass flows through the solids discharge openings from one cyclone cell to the other can be avoided. In many cases, this can be achieved to a good approximation by a proper design of the cell arrangement, the spacing between them, and the geometry of the housing inlet and outlet duct.

To compare both cyclone types, a typical industrial multiclone application has been considered and investigated in a systematic way. Various dedusting problems have been investigated, specified by the gas-solids feed, the available volume for the cyclone and its pressure drop.

In all considered cases, the gas feed per cyclone cell is 466 m^3/h (15,457 ft^3/h) air at ambient conditions with a gas density of $\rho_g = 1.2$ kg/m^3 and a gas viscosity of $\eta_g = 2 \times 10^{-5}$ Pa s.

With respect to the particle feed, only fine powders are taken into consideration in order to make a meaningful comparison. Note that the difference between both cyclone types becomes most clear when considering the collection of fine particles. With increasing particle size of the feed, the efficiencies of both cyclone types increase and converge (Figures 9 and 10). Four fine powders are considered characterized by

two different particle densities, ρ_S = 1,490 kg/m^3 and ρ_S = 2,700 kg/m^3, and two particle-size distributions $Q_3(d)$, which are assumed to be describable as Rosin-Rammler-Sperling-Bennett (RRSB) functions. The two sets of RRSB parameters are:

1. d_{min} = 0.2 μm, d_{max} = 200 μm, d' = 25.5 μm, n = 0.95, d_{50} = 17.5 μm
2. d_{min} = 0.1 μm, d_{max} = 30 μm, d' = 19 μm, n = 0.8, d_{50} = 12.2 μm.

In all considered cases the particle concentration is S_0 = 2 g/m^3.

The volume occupied by a cyclone is mainly determined by its diameter and by its length. A uniflow cyclone generally requires about the same or even a shorter length (typically 2–3 cyclone diameters) to achieve optimum performance than a swirl tube [*22*]. Thus, only the cyclone diameter is varied to observe the influence of the available volume. The swirl tube diameter $D_{c,ST}$ is varied between $D_{c,ST}/D_{c,UC}$ = 1.0 and $D_{c,ST}/D_{c,UC}$ = 1.3, while keeping the uniflow cyclone diameter constant at $D_{c,UC}$ = 124 mm. The pressure drop is varied between 500 Pa (0.073 psi) and 2,000 Pa (0.290 psi).

The results show that, under the operating conditions considered, a uniflow cyclone achieves a significantly higher separation efficiency than a swirl tube if the available volume is restricted to about the volume needed by the uniflow cyclone for separating the given gas-solids feed and if the available pressure drop is low, in accordance with experiments as is shown in Ref. 26. For example, for a pressure drop of 500 Pa, the efficiencies can differ by up to 10%. If the volume and pressure drop are freely available, swirl tubes reach higher separation rates than uniflow cyclones, with the separation efficiencies of both cyclone types converging as the gas-volume flow, and consequently, the cyclone size decreases and the pressure drop, the particle size or the particle density increase.

The results described here are transferable to multicyclone systems. In many cases multicyclones use swirl tube cells. Analogously, multicyclones can be made from uniflow cyclone cells. Often thse devices are used in space-limited applications; for example, as third-stage separators in fluid catalytic cracking (FCC) processes [*28, 29*].

Compared to swirl tubes, the higher efficiency per volume of uniflow cyclones at low pressure drop is especially advantageous in multicyclone applications with low pressure drop (for example purifying suction air in combustion engines [*27*]).

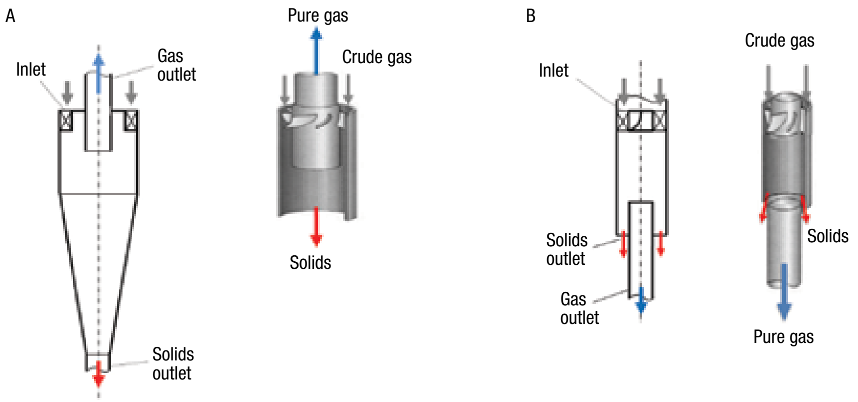

FIGURE 14. Swirl tube (standard cyclone with axial inlet) (a) and uniflow cyclone (b), applicable especially in multicyclones [*26*]

Concluding remarks

Comparing standard cyclones with uniflow cyclones by applying well proven calculation models for both cyclone types indicates higher efficiencies, but also higher volume required for properly designed standard cyclones. However, if available volume is restricted to about the volume needed by a uniflow cyclone for its optimum performance, and if the pressure drop is low, a uniflow cyclone can be more efficient,

in agreement with experiments. In other words, uniflow cyclones can achieve higher efficiencies per volume than standard cyclones if the available pressure drop is low. Furthermore, independent of any restriction regarding volume and pressure drop, the performance data of both cyclone types approach each other with decreasing gas-volume flow and increasing pressure drop, as well as particle size and particle density of the solids feed. Those results transfer to multicyclones systems consisting of many parallel cyclone cells. ■

Edited by Scott Jenkins

References

1. Gauthier, T.A., Briens, C.I., Bergougnou, M.A., Galtier, P., Uniflow cyclone efficiency study. *Powder Technol.,* 1990, p. 217–229.
2. Knowlton, T. M., Cyclone separators. In: Wen-Ching Yang (ed). "Handbook of Fluidization and Fluid-Particle Systems." Marcel-Dekker-Verlag, 2003.
3. Hoffmann, A.C. and Stein, L.E., "Gas Cyclones and Swirl Tubes," Springer-Verlag, 2nd ed., 2007.
4. Kox, V., Lehmann, C., Muschelknautz, U., Ripperger, S. VDI-Richtlinie: VDI 3676 Abgasreinigung – Massenkraftabscheider (2018), p. 1–39.
5. Barth, W., Berechnung und Auslegung von Zyklonabscheidern aufgrund neuerer Untersuchungen. Brennstoff-Wärme- Kraft, Bd. 8, Nr. 1, 1956, S. 1–9.
6. Muschelknautz, E., Brunner, K. Untersuchungen an Zyklonen. *Chem. Ing. Techn.* 39, Nr. 9/10, p. 531–538, 1967.
7. Muschelknautz, E. Die Berechnung von Zyklonabscheidern für Gase. *Chem. Ing. Techn.* 44, Nr. 1/2, 1972.
8. Muschelknautz E., Trefz M. Secondary flow and short circuit flow at the dust discharge end of cyclone separators. Calculation and design of multicyclones. 1. European Symposium Separation of Particles from Gases, Nürnberg, 19. bis 21.4.1989, Preprints S. 345–362.
9. Rentschler W. Abscheidung und Druckverlust des Gaszyklons in Abhängigkeit von der Staubbeladung. VDI Fortschritt- Berichte, VDI- Verlag, Düsseldorf, Reihe 3, Nr. 242, 1991.
10. Trefz M. Die verschiedenen Abscheidevorgänge im höher und hoch beladenen Gaszyklon unter besonderer Berücksichtigung der Sekundärströmung. VDI- Fortschr.-Ber., VDI- Verlag, Düsseldorf, Reihe 3, Nr. 295, 1992.
11. Greif, V. Reduzierung des Druckverlustes von Zyklonabscheidern durch Rückgewinnung der Drallenergie und Erweiterung der Grenzbeladungstheorie auf kleine und kleinste Staubbeladungen. VDI-Fortschr.-Ber., VDI-Verlag, Düsseldorf, Reihe 3, Nr. 470, 1996.
12. Muschelknautz, E., Greif, V. Cyclones and other gas-solids separators, in "Circulating Fluidized Beds" (Eds: J. R. Grace, A. A. Avidan, T. M. Knowlton), Blackie Acad. & Profess., London, p. 181–213. 1997.
13. Muschelknautz, U. Zyklone zum Abscheiden fester Partikel aus Gasen. VDI-Wärmeatlas, 12th ed., Springer, Berlin, Chapter 91-1, p. 1–20. 2018.
14. Muschelknautz, U., Muschelknautz, E. Abscheideleistung von Rückführzyklonen in Wirbelschichtfeuerungen. VGB KraftwerksTechnik 4/99.
15. Ipsen C., Roschek, D., Muschelknautz, U. Optimierung des Zyklonabscheiders einer zirkulierenden Wirbelschichtfeuerung – Theoretischer Hintergrund und Betriebserfahrungen. *VGB PowerTech Journal* 4/2014, S. 75–79.
16. Muschelknautz, U. Separation of coarse particles: New separator with low pressure drop. Proceedings of CFB-VII-Conference, Niagara Falls, Canada, 2002.
17. Würtl, R. Experimental investigation of uniflow cyclone performance. Diploma Thesis, MCI Management Center Innsbruck, Austria, 2007.
18. Foidl, F. Entwicklung von Leitapparaten zur Druckverlustminimierung in Gleich-stromzyklonen. Diploma Thesis, MCI Management Center Innsbruck, Austria, 2008.
19. Leitner, A. Einfluß der Staubart auf den Trenngrad eines Gleichstromzyklons. Diploma Thesis, MCI Management Center Innsbruck, Austria, 2009.
20. Reinalter, M. Minimierung des Partikelwiedereintrages in den Reingasstrom von Gleichstromzyklonen. Master Thesis, MCI Management Center Innsbruck, Austria, 2010.
21. Pattis, P. Entwicklung eines Gleichstromzyklons mit gezielter Strähnenführung. Master Thesis, MCI Management Center Innsbruck, Austria, 2010.
22. Muschelknautz, U., Pattis, P., Reinalter, M., Kraxner, M. Design criteria of uniflow cyclones for the separation of solid particles from gases. 10th International Conference on Circulating Fluidized Beds and Fluidization Technology – CFB-10, 2011.
23. Muschelknautz, U. Analytical approach for calculating the separation efficiency of uniflow cyclones. *Chem. Eng. Technol.* 35, 2012, No. 12, p. 2,099–2,106.
24. Muschelknautz, U. Analytical approach for calculating the performance data of uniflow cyclones. Proceedings oft he 22nd International Conference on Fluidized Bed Conversion, Turku, Finland, p. 929–934, 2015.
25. Muschelknautz, U. Performance comparison of uniflow cyclones and standard cyclones. Proceedings of the 12th International Conference of Fluidized Bed Technology, Krakau, Poland, 2017.
26. Muschelknautz, U. Design criteria of multi cyclones in a limited space. 8th World Congress on Particle Technology, Orlando, Fla., 2018.
27. Greif, V. Multizyklon-Blöcke zur Staubabscheidung vor Verbrennungsmotoren – Ausle-gung und Betriebserfahrungen. VDI-Berichte 1511, p. 215–226. Düsseldorf: VDI-Verlag, 1999.
28. Kraxner, M., Muschelknautz, U., Karri, S.B., Cocco, R., Knowlton, T.M. Applicability of a Uniflow Cyclone as a Third Stage Separator in the FCC-Process. AIChE – American Institute of Chemical Engineers – Annual Meeting, Minneapolis, Minn., USA, 2011.
29. Krishnamurthy, S., Koves, W. Apparatuses and methods for gas-solid separations using cyclones. UOP LLC, Patent US-8419835 B2, 2013.

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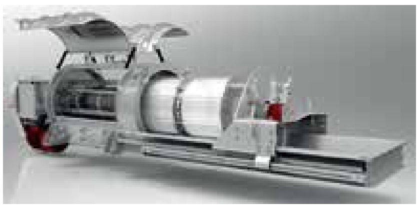
POWTECH 2019

Freeman Technology

Mettler-Toledo



Dinnissen Process Technology

Powtech 2019 (www.powtech.de) takes place from April 9–11 at the Exhibition Center in Nuremberg, Germany, where innovations and new approaches for the processing industries take center stage in six exhibition halls. Powder and bulk solids experts from around the world will be on hand to see the technology and solutions offered by exhibitors. Exhibitors will showcase their latest developments for mechanical processes, such as size reduction, agglomeration, separation, screening, mixing, storage and conveying. The equipment and machinery on display are fundamental to the production processes of numerous industries, including today's megatrends, such as energy storage and additive manufacturing (3-D printing).

Two forums and an interactive knowledge zone provide expert information for the food, pharmaceuticals and chemicals, glass and ceramics, non-metallic minerals and recycling segments. Here, and in the course of professional-level dialogue at the tradefair stands, visitors will get reliable answers to the challenges they face. Partec, the international congress for particle technology, will also run parallel to Powtech 2019 under the theme "Particles for a better life."

The following are some of the new products being exhibited at the show.

Instruments for characterizing powder materials

Now part of the Micromeritics Instrument Corp., this company will be showcasing its material characterization solutions designed to optimize process performance, increase productivity and improve quality in a diverse range of sectors. The company's portfolio (photo) includes the FT4 Powder Rheometer, a unique and comprehensive powder tester, which employs patented dynamic methodologies, automated shear cells (in accordance with ASTM D7891) and a series of bulk property tests to quantify powder behavior in terms of flow and processability. This is complemented by the Uniaxial Powder Tester, which provides accurate and repeatable measurements of the uniaxial unconfined yield strength (uUYS) of powders to assess and rank flowability. The company also offers in-line, realtime flow-measurement capabilities via an exclusive partnership with Lenterra Inc., a manufacturer of optical flow-sensor technology. Hall 4, Stand 547 — *Freeman Technology Ltd., Gloucestershire, U.K.*
www.powderflow.com

This technique significantly cuts costs for tank calibration

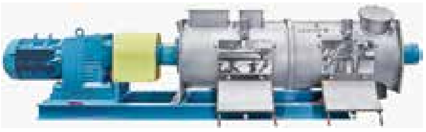
RapidCal Tank Scale Calibration (photo) replaces time-consuming and cumbersome test-weight, flowmeter or material-substitution methods. Instead, a downward force is applied with hydraulic equipment that mimics tank-scale loading during normal operation. By doing the calibration this way, piping- and understructure-influences are accounted for, and this provides higher calibration accuracy. The RapidCal reference system has an accuracy of 0.1%. Reference load cells provide traceability to applicable standards. RapidCal also avoids the tedious tank emptying and cleaning for material substitution, which in turn eliminates contamination risk and disposal costs. The effective downtime of a facility is limited to a few hours per calibration. There is no need for expensive deionized water, which has either to be disposed or stored after completion of the calibration. Hall 1, Stand 214 — *Mettler-Toledo GmbH, Gießen, Germany*
www.mt.com

A sifter that can be inspected in place, and is easy to maintain

The engineers at this company have developed a new sifter with improved inspection methods to prevent cross-contamination. The Wingdoor sifter (photo) is a combination of innovative power and the sieving process. The major advantage of this machine is that the doors can now open over the entire length of the machine. Therefore, the sieve does not need to be driven out for inspection, so that cross-contamination is prevented. The replacement of the sieve mesh is said to be very efficient, because the sieve basket can still be slid out of the machine. In addition, the Wingdoor sifter can reach capacities of up to 30 metric tons per

hour, depending on the product. Hall 4, Stand 371 — *Dinnissen Process Technology, Sevenum, the Netherlands*
www.dinnissen.nl

A continuous mixer that has many features



Gebr. Lödige Maschinenbau

The continuous Ploughshare mixer KM (photo) is suitable for processing powdery, fibrous or granular solids, as well as liquids and pastes. Granulation processes can also be carried out with the continuous mixer. The mixer is based on a patented, mechanically generated, turbulent fluidized-bed process. During this process, the Ploughshare shovels rotate close to the wall in a horizontal, cylindrical drum. Their peripheral speed and geometric shape are rated such that they take the mixing components off the drum wall and toss them into the free-mixing compartment from the product bed. Due to the continuous mixing of the entire product, intensive blending is thus achieved. Transport of the product is ensured by the special shape and arrangement of the mixing elements. Excellent homogeneity and consistent reproducibility of the final product are achieved during short mixing or retention times of only 25–60 s. The smallest model has a drum capacity of 5 L and a throughput capacity of 0.25 m^3/h, depending on retention time and filling level. The largest machine built to date has a drum capacity of 57,000 L, and has been in operation at an Indian steelworks since 2015. There, it mixes and granulates the sintering material needed in the blast furnace for pig-iron production, and can handle more than 1,350 metric tons of raw sintering mixture per hour. Hall 1, Stand 517 — *Gebr. Lödige Maschinenbau GmbH, Paderborn, Germany*
www.loedige.de

Conveying and processing equipment for solids

Dynamic Air

This company will be exhibiting an operating pneumatic conveying system, as well as the Bella twin-shaft mixer and vibratory equipment. The company manufactures a complete line of dense- and dilute-phase, vacuum- and pressure-pneumatic conveying systems, process equipment and vibratory equipment for handling a wide variety of dry bulk-granular materials. A fully operational dense-phase pneumatic-conveying system will be on display, along with the Bella XN double-shafted mixer in 304 stainless-steel food-grade design.

This mixer provides a high-quality blend in an extremely short mixing time, says the manufacturer. Also on display will be the company's line of vibratory equipment, including the Stedi-Flo vibratory pan feeder and the GYRO EX bin activating feeder and discharger (photo, p. 65), which produces a controlled gyratory motion to positively withdraw granular materials from bins, storage silos and hoppers at any desired feedrate for a consistent and reliable discharge. Hall 2, Stand 319 — *Dynamic Air Ltd., Milton Keynes, U.K.*
www.dynamicair.com

See inflatable-seated butterfly valves in operation

This company manufactures a complete line of inflatable-seated butterfly valves (photo) for handling a wide variety of dry bulk-granular solids, liquids and gases. Standard sizes are from 2 to 30 in. (5 to 750 mm), and fit both ANSI and metric flanges. They are offered in a wide variety of construction materials, including stainless steel, ductile iron and aluminum. Standard finishes include urethane coating, nylon powder coating, epoxy coating, highly polished stainless-steel discs and bodies, plus almost any custom paint type and color. Various finishes are also available, from custom coatings to highly polished surfaces. The inflatable-seat design provides a better seal by utilizing air pressure to expand the seat against the disc, providing more sealing area and an even pressure distribution against the disc every time. The seat automatically compensates for wear when it inflates against the disc, extending valve life considerably. At the stand, the company will be exhibiting a heavy-duty inflatable seated butterfly valve operating next to a typical resilient-seated valve to demonstrate how quickly a resilient-seated valve can wear, in comparison to the air-operated valve. Hall 2, Stand 326 — *Posi-flate, Milton Keynes, U.K.*
www.posiflate.com

Posi-flate

A spray-drying plant for bio-based products

GEA

This company recently supplied a turnkey plant for the spray drying of lignosulfonate in Norway (photo). The

solution also includes a new silo for feeding stored powder materials into the plant's packaging system and a large wet scrubber for de-dusting. At this plant, 25 ton/h of lignosulfonates is directly fed into a rotary atomizer and spray dried. The final product is separated in two groups of consecutive cyclones. The second newly developed cyclones CEE (Cyclone Extra Efficiency) offer a higher separation efficiency, which increases the yield and reduces emissions. In real-world tests, the CEE powder separation efficiency was verified as being considerably higher than the efficiency of standard cyclones. Part of the spray drying plant is the large wet scrubber for de-dusting. The Venturi scrubber uses water to clean the exhaust gases from the spray dryer before they are released into the environment. The scrubbing water is circulated and fed continuously to a falling-film evaporator for concentration and recovery of valuable substances. The condensate is returned to the spray dryer as process water, and thus increases the total product yield while the concentrate is discharged. The evaporator is designed for 2 h/ton of scrubbing water and energetically optimized by heating through mechanical vapor recompression. Hall 3, Stand 231 — *GEA, Düsseldorf, Germany*
www.gea.com

Fine and powerful comminution with maximum flexibility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The high-speed Universal Cutting Mill Pulverisette 19 comminutes up to 60 L/h of soft to medium-hard sample materials and fibrous materials at a torque of up to 30 Nm with reliable, reproducible results. The variable rotational speed adjustment, in increments of 100 between 300 and 3,000 rpm, enables fine tuning of the comminution process for each sample within a very wide range of applications. A low-speed version has a variable rotational speed adjustment between 50 and 700 rpm and a torque of up to 67 Nm. The combination of low cutting rate and extreme cutting forces enables a very powerful comminution of hard, tough-elastic samples and small sample quantities. At the same time, it is suitable for all cases where thermal damage, the loss of highly volatile substances, or an excessively high fine share need to be avoided, says the company. The cutting mills can be combined with a cyclone separator (photo) for sample recovery, and an optional exhaust system. The cyclone separator is completely made of stainless steel 304. Hall 2, Stand 227 — *Fritsch GmbH, Idar-Oberstein, Germany*
www.fritsch.de

Gerald Ondrey

INTERPHEX


Frewitt USA

PSL


Optima Pharma

Interphex 2019 will take place April 2–4 at the Jacob Javits Convention Center in New York City. Focused on biotechnology and pharmaceutical manufacturing, Interphex will feature a large exhibit hall and a technical conference with session tracks covering flexible manufacturing, process optimization, risk management and more. For the first time, Interphex will collaborate with Integrated Project Services, LLC (IPS; Blue Bell, Pa.; www.ipsdb.com), a provider of engineering, procurement and construction management (EPCM) services, to debut Innophex, a new event dedicated to innovation and technology commercialization. Co-located with Interphex, Innophex will bring its own exhibitors and technical content to showcase a variety of emerging technologies for gene therapy and cell processing, including robotics, 3-D printing, augmented reality and other Internet of Things (IoT) technologies. The following is a small selection of the products and services that will be showcased at Interphex 2019.

This modular milling system has nano-scale capabilities

The FreDrive-Lab is a modular milling system for research, formulation and analytical laboratories in the pharmaceutical, cosmetic, fine chemical and food industries. This patented system integrates six different milling processes into one system, enabling the user to produce a wide variety of particle sizes ranging down to a lower particle-size distribution spectrum of $D_{90} < 10$ µm. The latest addition to the FreDrive-Lab product family, the NanoWitt high-performance bead mill (photo), expands the range's capabilities for particle-size reduction, enabling wet nano-milling down to 50 nm. Booth 2865 — *Frewitt USA Inc., Hillsborough, N.J.*
www.frewitt.com

Lab-scale filtration and drying in one step

The GFD range of laboratory filter dryers (photo) combines filtration, solids isolation, cake washing and vacuum drying into a single step. The GFD range has recently been expanded with two new models: the GFD Lab and GFD Lab PLUS, which provide additional configuration options in terms of vessel capacity and automation. Stainless-steel vessels are offered for high-pressure applications. The vessel has a heated jacket for efficient drying and a removable filtration basket for simplified product collection. The GFD can be integrated into fume hoods while maintaining process visibility, batch homogeneity and reduced product exposure. The GFD Lab PLUS model includes a digital display and touchscreen to show realtime values and graphs, as well as recipe inputs and sequencing. The GFD is compatible for microsphere separation or purification. The agitated Nutsche-filter dryer technology and distinctive agitator design enable effective cake agitation in many applications, including production of dyes and paints, wastewater treatment and pharmaceutical production. Booth 2322 — *Powder Systems Ltd. (PSL), Liverpool, U.K.*
www.powdersystems.com

Turnkey solutions for complex production environments

The MultiUse line of automated processing machines are highly flexible and fully automated to handle very specialized or valuable products in different delivery formats. The filler machine from the MultiUse product line is suitable for laboratory applications, as well as small- to medium-batch operations, and can be quickly converted for processing different product formats and container types, says the manufacturer. The company also offers a variety of turnkey services for complex production systems (photo), including filling and closing technologies, isolation and freeze drying. This includes digitalized planning, from the integrated factory acceptance test (iFAT), site management and the site acceptance test (SAT) and comprehensive services utilizing engineering technologies, such as flow visualization. Also on display will be the new CS freeze dryer, which is tailored to products that are new to the market and are initially produced in small and medium quantities. The space-saving CS freeze dryer is optimized for installation in existing buildings. Booth 3013 — *Optima Pharma GmbH, Schwäbisch Hall, Germany*
www.optima-packaging.com

ChargePoint Technology

Bürkert

Smart valve monitoring for hazardous locations

This company has achieved hazardous-area certification (Class 1 Zone 0 and Class II/III Zone 21) from the Canadian Standards Association (CSA) for its Verifi smart-monitoring hub (photo). The Verifi system monitors usage of this company's split butterfly valves (SBVs), which provide containment during manufacturing processes and are designed to increase sterility assurance for ingredient and small-component transfers in aseptic processing. Verifi continuously records valve use and provides data to proactively manage and maintain containment solutions, which helps to improve operator safety and risk management. The Verifi system already holds atmosphere explosive (ATEX) and International Electrotechnical Commission (IEC) explosive (Ex) certifications, allowing the use of Verifi in hazardous environments in Europe. Booth 3033 — *ChargePoint Technology Inc., Forked River, N.J.*

www.thechargepoint.com

These flow sensors provide many measurement parameters

FLOWave sensors (photos) are operated using the patented surface acoustic wave (SAW) technology. With SAW-enabled flowmeters, there are no installed fittings or constrictions, which also means that there are no empty spaces in the measuring tube. In addition, there is no contact between the sensor elements and the medium, making the process appropriate for hygienic applications. Incorporating various measurement parameters into one sensor reduces the number of contamination-prone screw connections in the plant. In addition to flow measurement, these sensors provide integrated gas-bubble detection, which ensures fast response in the event of process faults. A density factor enables the quick identification of fluid changeovers, and viscosity compensation facilitates precision with high-viscosity fluids. Booth 3553 — *Bürkert Fluid Control Systems, Ingelfingen, Germany*

www.burkert.com

Filling and closing machines for ready-to-use vials

The Dara NFL/2-RDL aseptic filling and closing machine for ready-to-use vials (photo) handles nests of pre-sterilized vials and avoids the crimping required with traditional aluminum closures. This fully servo-driven system streamlines packaging operations to minimize equipment footprint and changeover time. The Dara NFL/2-RDL can be used from scaleup through small-batch commercial manufacturing. Utilizing ready-to-use vials simplifies small-scale production by eliminating the need for a washer and depyrogenation tunnel, according to the manufacturer. NFL/2-RDL systems are designed to seal vials with ARaymondlife's patented RayDyLyo caps, which are pre-assembled plastic closures featuring a rubber stopper within the cap to minimize the "pop-off" effect and eliminate the risk of stoppers adhering to freeze-dryer plates. RayDyLyo closures come in 13- and 20-mm sizes. Booth 2353 — *NJM Packaging, Lebanon, N.H.*

www.njmpackaging.com

This modular feeder design enables fast process adaptation

The new K3-PH line of loss-in-weight screw feeders (photo) is designed for continuous processing applications in the pharmaceutical industry. The new feeder features a modular concept with a drastically reduced overall footprint thanks to a new, smaller platform scale that incorporates the patented Smart Force Transducer (SFT) weighing technology. The modular quick-change design allows the easy exchange of feeder types and sizes, as well as hoppers or agitators using the same scale and drive for fast adaptation to new processes and formulations while also ensuring easy cleaning and maintenance. The new device is suitable for multi-feeder clustering in a variety of continuous processes, including direct compression, continuous extrusion, wet and dry granulation and continuous coating, as well as traditional batch processes. Booth 2558 — *Coperion K-Tron, Sewell, N.J.*

www.coperion.com/pharma ■

Mary Page Bailey

NJM Packaging

Coperion K-Tron

Economic Indicators

2016 2017 2018

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Dec. '18 Prelim.	Nov. '18 Final	Dec. '17 Final
CE Index	616.0	616.5	572.9
Equipment	751.3	752.3	691.8
Heat exchangers & tanks	667.3	671.4	604.9
Process machinery	731.7	732.6	694.0
Pipe, valves & fittings	979.9	973.6	893.5
Process instruments	420.3	420.8	410.7
Pumps & compressors	1037.3	1036.3	996.4
Electrical equipment	553.7	552.8	524.1
Structural supports & misc.	827.2	832.5	732.7
Construction labor	339.6	338.2	330.4
Buildings	600.1	600.7	567.4
Engineering & supervision	316.6	317.1	308.9

Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

Annual Index:

2010 = 550.8

2011 = 585.7

2012 = 584.6

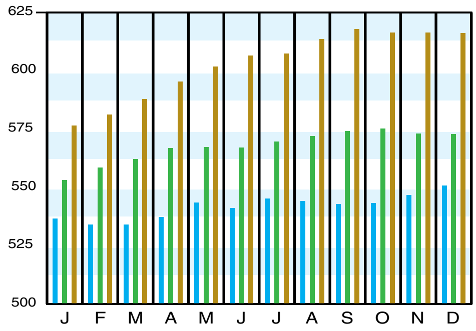
2013 = 567.3

2014 = 576.1

2015 = 556.8

2016 = 541.7

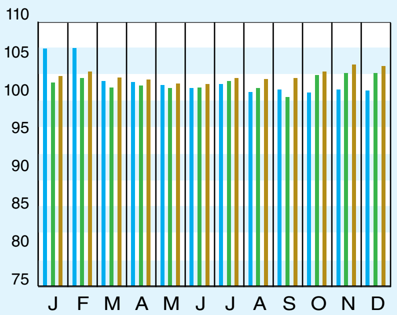
2017 = 567.5



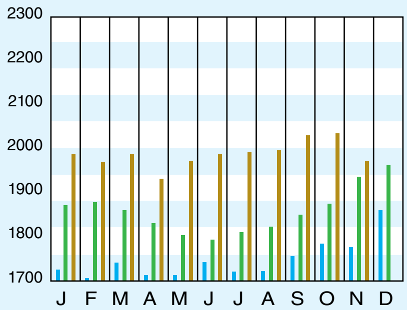
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	Jan. '19 = 104.1	Dec. '18 = 104.2	Nov. '18 = 103.7	Jan. '18 = 100.4
CPI value of output, $ billions	Nov. '18 = 1,971.9	Oct. '18 = 2,031.8	Sept. '18 = 2,029.1	Nov. '17 = 1,892.6
CPI operating rate, %	Jan. '19 = 77.2	Dec. '18 = 77.3	Nov. '18 = 77.0	Dec. '17 = 75.1
Producer prices, industrial chemicals (1982 = 100)	Jan. '19 = 249.7	Dec. '18 = 260.7	Nov. '18 = 279.2	Dec. '17 = 268.1
Industrial Production in Manufacturing (2012 =100)*	Jan. '19 = 105.2	Dec. '18 = 106.1	Nov. '18 = 105.3	Dec. '17 = 102.3
Hourly earnings index, chemical & allied products (1992 = 100)	Jan. '19 = 188.4	Dec. '18 = 186.7	Nov. '18 = 187.3	Dec. '17 = 187.3
Productivity index, chemicals & allied products (1992 = 100)	Jan. '19 = 96.2	Dec. '18 = 97.0	Nov. '18 = 97.0	Dec. '17 = 95.7

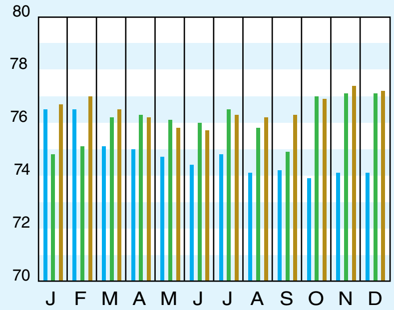
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the December 2018 *CE* Plant Cost Index (CEPCI; top; most recent available) decreased from the previous month's value. This small decline follows an unchanged CEPCI value from November. The Equipment, Buildings and Engineering & Supervision subindexes all fell slightly for December 2018, while the Construction Labor subindex increased by a small margin. The overall CEPCI value for December 2018 remains at 7.5% higher than the corresponding value from December 2017. Meanwhile, the CBI numbers (middle) show a small decrease in the CPI Output Index for January 2019, and a decrease in CPI Value of Output for November of last year, the most recent value available.